PB-215 323

RECLAMATION OF RE-USABLE WATER FROM SEWAGE

Rolf Eliassen, et al

Stanford University
Stanford, California

August 1964

DISTRIBUTED BY:

NTIS

National Technical Information Service
U. S. DEPARTMENT OF COMMERCE
5285 Port Royal Road, Springfield Va. 22151

WPD-21-02-64

WPD 21-02-64 (Eliassen)

August 1964
Technical Report No. 41

PB 215 323

Progress Report

RECLAMATION OF RE-USABLE WATER FROM SEWAGE

Rolf Eliassen, Project Director

and

Bruce M. Wyckoff

Reproduced by
NATIONAL TECHNICAL
INFORMATION SERVICE
U S Department of Commerce
Springfield VA 22151

PHS Demonstration Grant WPD-21-02-64

Division of Water Supply and Pollution Control

Public Health Service

July 16, 1963 to July 15, 1964

Department of CIVIL ENGINEERING
STANFORD UNIVERSITY

60

PROGRESS REPORT

RECLAMATION OF RE-USABLE WATER FROM SEWAGE

DEMONSTRATION PROJECT GRANT

NO. WPD-21-02

Rolf Eliassen, Project Director

and

Bruce M. Wyckoff

Stanford University

Stanford, California

Details of illustrations in
this document may be better
studied on microfiche

Covering the Period

July 16, 1963 to July 15, 1964

August 1964

RECLAMATION OF RE-USABLE WATER FROM SEWAGE

Demonstration Project Grant NO. WPD-21-02

SUMMARY

In laboratory studies, various processes were tried for further treatment of effluent from a laboratory scale activated sludge plant. Ion exchange has been utilized with different resins and in different configurations to remove nutrients, nitrogen and phosphorus, and also organic materials. A strong-base ion exchange resin, regenerated with chlorides, was the most successful. Phosphorus and color were removed by chemical coagulation using liquid alum and commercial ferric sulfate as coagulants. The effect of foam fractionation on ABS and COD removal and on the form of nitrogen was studied. In addition, nitrogen removal by a denitrification process was also studied.

The installation of a pilot plant to test the various processes in the reclamation of water from sewage treatment plant effluent at a 10 gpm scale is substantially complete. Units installed include an activated sludge sewage treatment plant, chemical treatment unit, sand filter, diatomaceous earth filter, ion exchange unit, and a small pond to receive the treated water. The removal of nitrogen, phosphorus, organic materials and virus will be studied in the pilot plant during the coming year.

TABLE OF CONTENTS

Item	Page
SUMMARY	i
STATEMENT OF PROGRESS	1
LABORATORY PROGRAM	2
Ion Exchange Studies	3
Procedure	3
Strong-Base Resin	4
Weak-Base Resin	4
90% Strong-Base, 10% Weak-Base	6
Regeneration	8
Resin Fouling and Restoration	10
Use of Sea Water as Regenerant	13
High Chlorides in Influent	13
Use of Unfiltered Effluent	16
Dual Bed with Weak-Base Resin	16
Ion Balance and Resin Capacity	18
Waste Disposal	19
Cost	19
Continuous Run	21
Chemical Precipitation	22
Foam Fractionation	28
ABS Removal	28
COD Removal	30
Nitrogen Removal	32
Denitrification Studies	33
Activated Carbon Studies	39
Chemical Coagulation before Activated Sludge	41
Lake Lagunita	41
PILOT PLANT PROGRAM	43
Activated Sludge Sewage Treatment Plant	44
Chemical Treatment Unit	46
Sand Filter	47

Diatomaceous Earth Filter 48
Ion Exchange Unit 49
Pond 50

DEMONSTRATION PLAN 51

PROFESSIONAL STAFF 52

REPORTS AND ARTICLES 53

ACKNOWLEDGMENTS 54

REFERENCES 55

STATEMENT OF PROGRESS

The objective of this project is to demonstrate the feasibility of using tertiary and advanced treatment techniques in the reclamation of water from sewage. There exists at Palo Alto, California, a unique opportunity to do this. An ample supply of treated sewage exists at Palo Alto, which could be reclaimed and pumped to Stanford University, which is short of water. The reclaimed water could be put into Lake Lagunita on campus and used for recharge to ground water supplies, irrigation and recreational uses. In order to do this, water of high quality would have to be produced, approaching drinking water standards. In addition, either nitrogen, phosphorus, or both, would have to be removed in order to limit the growth of algae in the lake itself.

The program is being approached in three phases. The first phase consists of laboratory studies to be used as the basis for the second phase, construction of a pilot scale model at the Palo Alto Sewage Treatment Plant. The third phase would be the full-scale water reclamation plant to provide re-usable water for Stanford. The current study, supported by the Public Health Service, includes phases 1 and 2.

LABORATORY PROGRAM

The laboratory studies are almost complete; work continues only with a continuous run ion exchange unit. Studies with phosphorus removal by chemical coagulation, nitrogen removal by denitrification, removal of ABS and other organics by foaming, removal of ABS and other organics with activated carbon, and all ion exchange work except the continuous run are reported herein. Also described in this report is an attempt to apply chemical treatment before the activated sludge process and some monitoring studies at Lake Lagunita.

ION EXCHANGE STUDIES

Ion exchange studies were instituted in an attempt to develop a method which would remove the nutrients, nitrogen and phosphorus, from treated sewage and in addition, remove organic material. Phosphorus in sewage occurs as phosphates and may be removed by an anion or negative ion exchange. Nitrogen occurs in sewage mainly as ammonia and organic nitrogen, but through treatment is oxidized to nitrites and nitrates. Assuming treatment of sewage is relatively complete, nitrogen also may then be removed by an anion exchange as nitrites and nitrates.

Organic materials often are adsorbed on anion resins, occupying exchange sites and thus fouling the resin. By taking advantage of this tendency to adsorb organics, organics may be removed from treated sewage. The feasibility of the method will depend upon subsequent removal from the resin of adsorbed organics by special treatments. Treatment using a strong-base resin was very successful and will be described first in the following sections of this report.

Procedure

Ion exchange resins were used in 50-ml burettes. Flow was controlled with the burette stopcock and measured with a flow meter. Influent was stored in 2-liter polyethylene aspirator bottles with rubber tubing arranged so that watertight connections would be made to the top of the burette, and a head of several feet was available for forcing the flow through the resin. Flow was downward through the bed of resin and was controlled at about 10.5 bed volumes per hour, which would correspond to 1.6 gpm/ft^2 (6.6 ml/min/cm^2). Initial column length was 15 inches (38 cm), corresponding to a resin volume of 33 cm^3.

The influent used was secondary effluent from a laboratory activated sludge unit, receiving raw sewage at conventional loadings. The influent was sand filtered prior to ion exchange.

When the resin bed became exhausted, it was backwashed with flow upwards through the bed. Regeneration with chlorides followed using

downflow, followed by a rinse. Samples were taken after passage of each two liters through the resin, usually five such samples could be obtained per run prior to bed exhaustion.

Strong-Base Resin

The most promising resin used was the strong-base anion exchanger, Duolite A-102D, as manufactured by the Diamond Alkali Company. This resin is Type 2 with quaternary ammonium functional groups superimposed upon a cross-linked polystyrene matrix. It is highly porous and comes in bead form.

Results of five runs to exhaustion of this resin are shown in Figure 1, and include about 1600 bed volume of throughput. Individual runs varied considerably, principally due to variation in the composition of the treated sewage, so composites of several runs were found to be more meaningful than individual runs. Variation in results between runs could also have been caused by changes in flow rate and resting of resin between samples. Regeneration was achieved using 2 bed volumes of 10 percent sodium chloride.

Removals of phosphorus and nitrogen were excellent to over 200 bed volumes of flow in each run. Nitrites broke through somewhat early, but quantities of nitrite in the treated sewage were small in any case. Significant amounts of organic materials were also removed as evidenced by the removal of color, COD and ABS.

Since chloride exchange was used, chlorides were added to the effluent while other ions were removed. The chloride content in the effluent decreased as the run progressed, and removals of the other ions decreased.

Table 1 shows the average of the treated sewage influent concentrations to the ion exchange resins which correspond to data shown in Fig. 1, and several other figures.

Weak-Base Resin

A weak-base anion exchange resin, Duolite A-7, also was tried. This resin has a porous phenolic matrix and amine functional groups and comes in granular form.

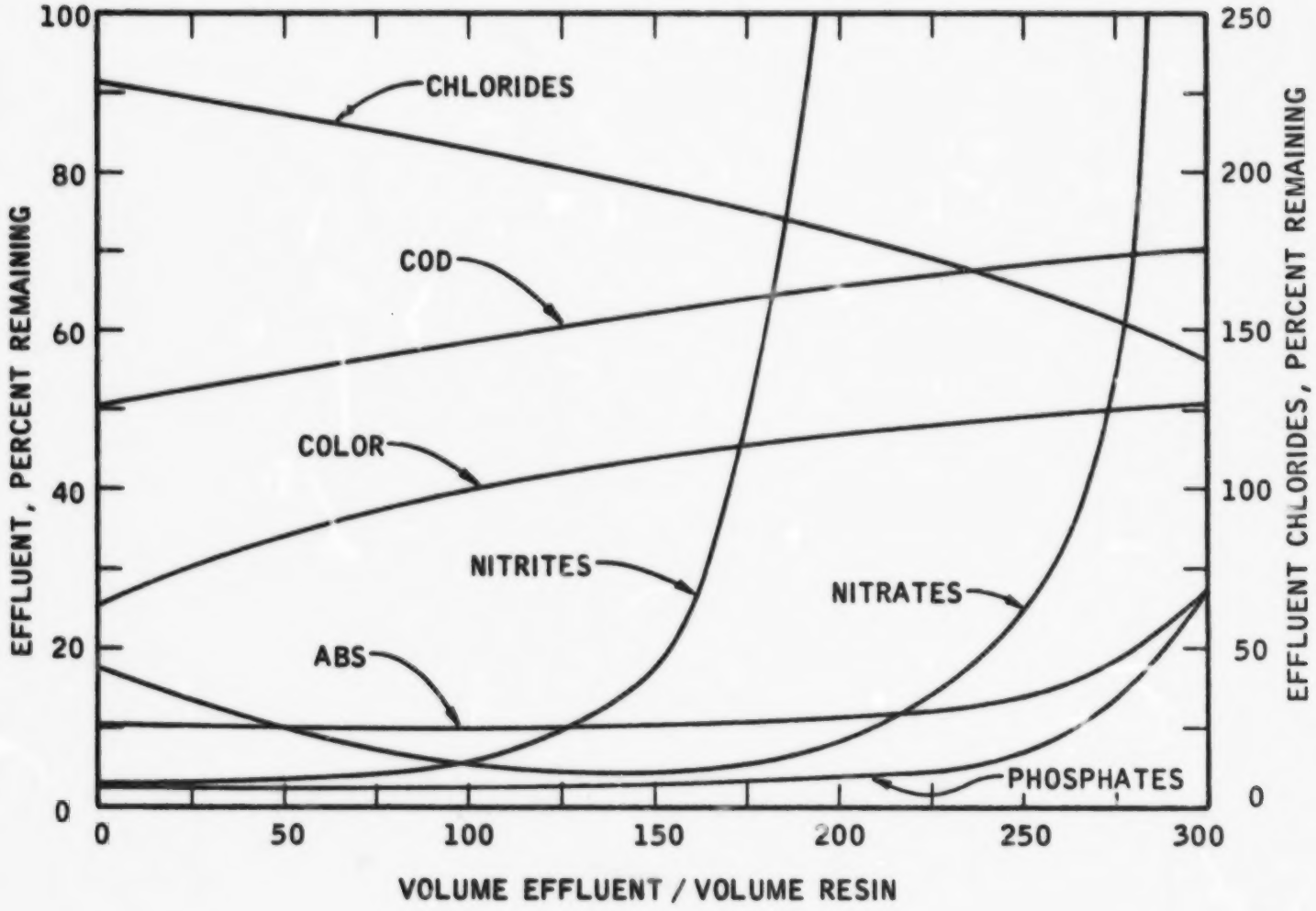


Fig. 1 - Strong-Base Resin

TABLE 1

INFLUENT COMPOSITION, mg/l

	Fig. 1	Fig. 2	Fig. 3	Fig. 5	Fig. 6	Fig. 7
Phosphate (as P)	7.6	8.5	11.1	7.6	7.8	9.1
Nitrate (as N)	18.4	16.8	13.6	21.3	25.5	12.4
Nitrite (as N)	1.06	1.00	2.5	0.76	0.22	0.72
COD	33	36	40	26	62	29
ABS	1.10	0.94	1.65	1.00	0.88	0.98
Color (units)	65	58	55	39	34	24
Chlorides	128	110	310	$\binom{117}{520}$	138	131

Results of the average of two runs to exhaustion including 600 bed volumes of throughput are shown in Figure 2. Influent characteristics are shown in Table 1. Regeneration was performed using 2 bed volumes of 1-normal sodium hydroxide followed by 2 bed volumes of 1-normal hydrochloric acid.

Good removal of nitrogen was achieved, but performance on phosphorus was poor. Breakthrough of phosphates occurred early and concentration in the effluent increased rapidly thereafter. Since phosphorus may be the key element in algae control, the use of the weak-base resin was abandoned in favor of the strong-base resin.

The weak-base resin did a much better job in removing organic material. COD and ABS removals were better than those for the strong-base resin, and almost all color was consistently removed. The high affinity for color exhibited by the weak-base resin is probably due to its porosity and ability to absorb acids, as color is commonly believed to be caused by organic acids of high molecular weight. Chlorides were increased while the other ions were decreased as with the strong-base resin, except that chlorides were higher with the weak than with the strong-base resin. This is due to hydrolysis of the HCl from the resin during adsorption.

90% Strong-Base, 10% Weak-Base

In order to take advantage of the A-7 weak-base resin's high affinity for color, and the A-102D strong-base resin's good phosphate

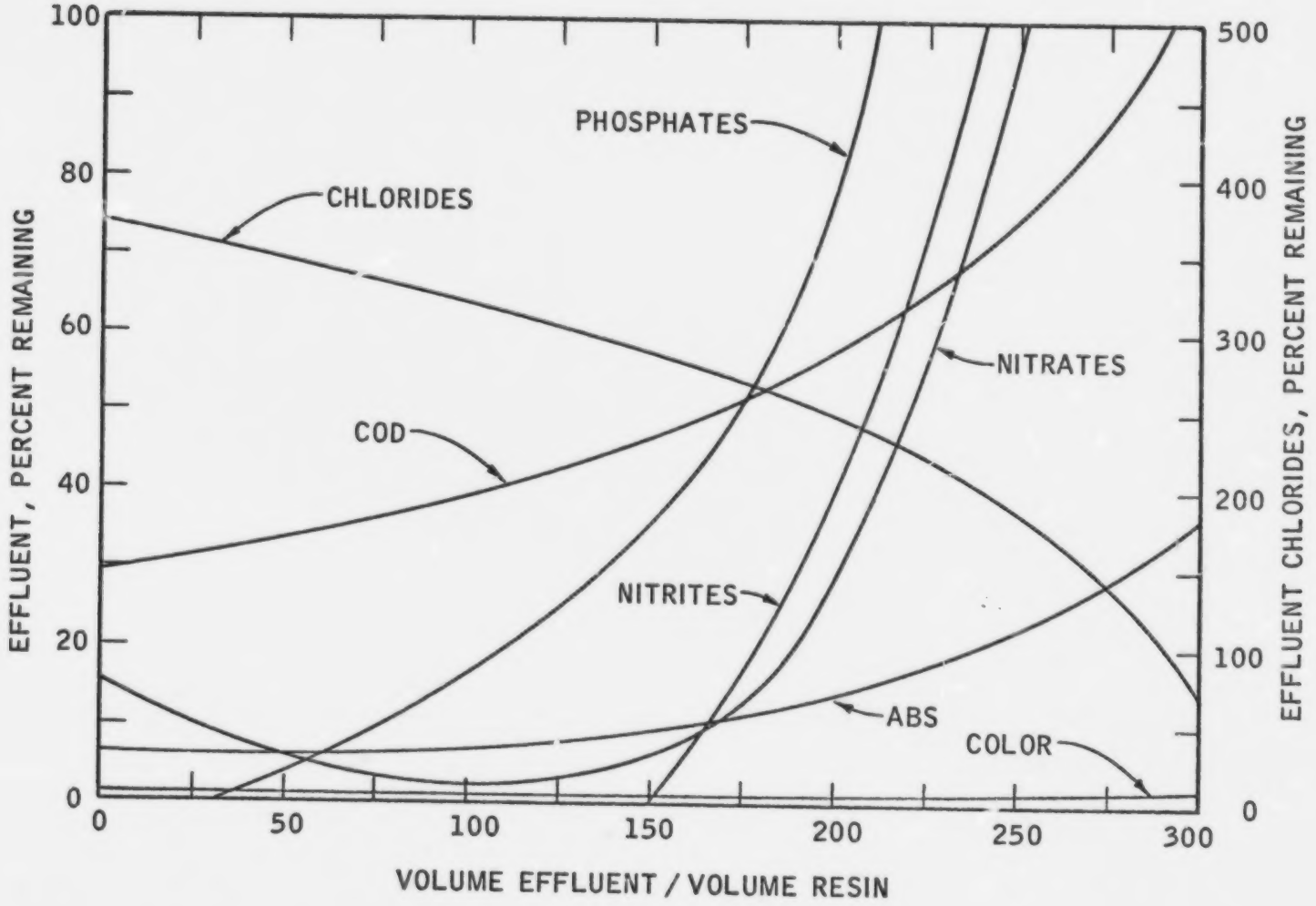


Fig. 2 - Weak-Base Resin

removal qualities, a combination of the two resins was tried. The mixture chosen was 90% A-102D and 10% A-7. The results of five runs to exhaustion are shown in Fig. 7. Removal of color, particularly early in the run, was improved. Nitrite removal was somewhat better than that shown by A-102D alone, but nitrate removal was not good. The increase in chlorides was excessive, particularly early in the run. It is concluded that combining resins in this manner is not advantageous. Influent concentrations are shown in Table 1.

Regeneration

By the very nature of ion exchange, as one ion is removed from solution, it is replaced by another. As the ion exchange operation proceeds, the resin becomes charged with ions which are being removed from solution and the regenerant ions are released. At the end of a run the resin must be regenerated to remove the ions which were removed from the water. To accomplish this, a high concentration of the regenerant solution is passed over the resin.

Desired characteristics for a regenerant anion are:

1. An ion which is innocuous in water
2. An ion which is held less strongly to the resin than ions which are to be removed from water
3. Low cost.

The chloride ion is one available which most closely approaches these requirements. The cost is low. When used with a strong-base resin, it is quite effective in removing undesirable ions. In low concentrations, it is quite harmless.

However, in high concentrations chlorides can be objectionable. The U.S. Public Health Service Drinking Water Standards [Ref. 1] limit chlorides to 250 mg/l. This is based on the fact that taste is imparted to water for some people above this concentration. Chlorides can be detrimental to water meant for agricultural use also. Although there are some crops which are sensitive to an excessive chloride concentration, the principal effect of chlorides is to increase salinity which tends to inhibit the osmotic pressure the plant is able to exert [Ref. 2]. An ion exchange process does not necessarily increase salinity as one ion is exchanged for another.

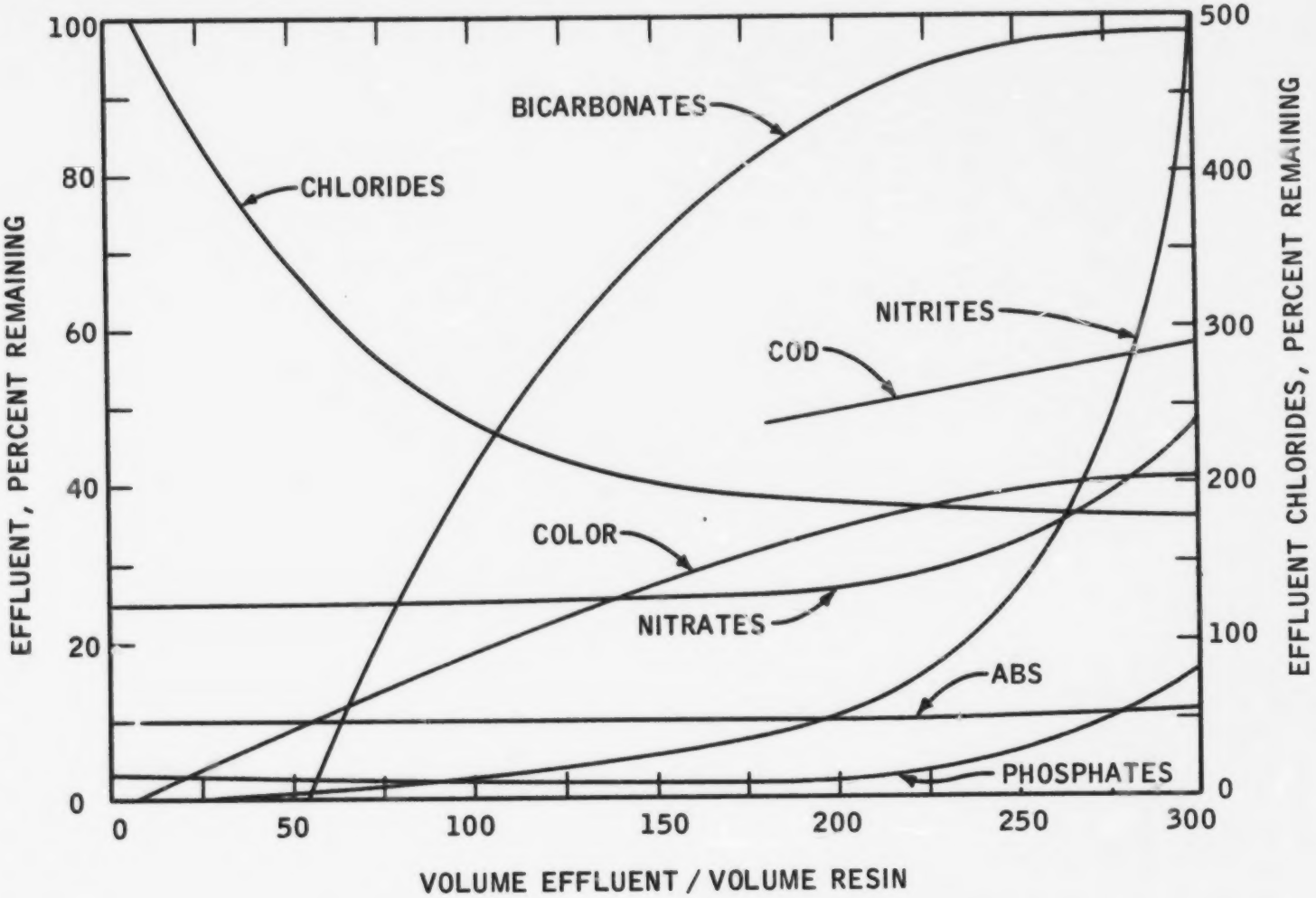


Fig. 7 - 90% Strong-Base Resin & 10% Weak-Base Resin

Unfortunately, Palo Alto sewage, upon which all tests have been run, is high in chlorides. This is apparently due to infiltration of sea water into low-lying sewer lines. The average chloride content at the effluent of the runs shown in Fig. 1 prior to breakthrough was just over the 250 mg/l standard for drinking water. Tests on a sewage lower in chlorides concentration than Palo Alto sewage would probably be more favorable. Not only would chlorides in the effluent be lower, but performance in removing other ions would be improved. The effect of high chlorides and the use of sea water as a regenerant and source of chlorides are discussed later.

Another regenerant which is often used with an anion resin is the hydroxide ion. Unless the hydroxide ions are not objectionable in the treated water, a cation resin regenerated with acid is also used and the hydrogen ion released from the cationic resin, and hydroxide ion released from the anionic resin, combine to form water. This is the deionization procedure. Deionization could be used with treated sewage, but it is likely to be quite expensive. Two resins are required and both the acid and base regenerants are expensive.

The chloride content in the influent has an effect on removals and length of runs as mentioned above and discussed later. Another ion which has a profound effect on the process is the sulfate ion. Sulfates are almost completely removed by the strong-base resin and are removed after other ions begin to break through. This means that the exchange which takes place, and therefore the chlorides added, are strongly influenced by the sulfates in the water. The length of run is likewise greatly influenced by sulfate content. The sulfate content of Palo Alto sewage ranged from 43 to 104 mg/l and was usually between 50 and 70 mg/l.

Resin Fouling and Restoration

Some organic material is adsorbed on an anion exchange resin and not removed by normal regeneration. This material occupies exchange sites, lowering the exchange which can take place, thus fouling the resin. In order to make ion exchange attractive economically, some method must be found for removing this organic material.

Figure 4 shows phosphate removals using one bed of strongly basic Duolite A-102D. Each curve represents the average phosphate remaining in several runs ending with the quantity of flow shown. The curve for 1,600 bed volumes is identical with that shown in Fig. 1. By the time 4,900 bed volumes had been reached, capacity of the resin had been considerably reduced as evidenced by the pronounced shift to the left. Removals before breakthrough were uniformly good. Influent phosphates are shown in Table 2. Resin regeneration was performed using 2 bed volumes of 10 percent sodium chloride.

TABLE 2

INFLUENT PHOSPHATE (FIG. 4)

Curve	Phosphate (as P) mg/l
1600 bed volumes	7.6
3100	8.3
4900	7.8
6700	6.4

Two methods of resin restoration were tried in an effort to restore the resin to its virgin capacity. The first was the method used by Abrams and Lewon [Ref. 3] to remove ABS from a fouled resin. This involved using a mixture of five bed volumes each of methanol and 1-normal hydrochloric acid at a temperature of 46°C. The second method was one commonly used in the past to remove silica, a material not removed by chlorides [Ref. 4]. This treatment used 4 bed volumes of 1-normal sodium hydroxide at a temperature of 38°C.

The curve for 6,700 bed volumes in Fig. 4 shows results following both restoration treatments. Considerable improvement is obvious. Unfortunately, two runs to exhaustion between the two restoration attempts failed to indicate how much improvement should be ascribed to each treatment. The first run had high chlorides in the influent and all removals were poor for that reason. One critical sample was lost from the second run. Future work will hopefully show the effectiveness of each method.

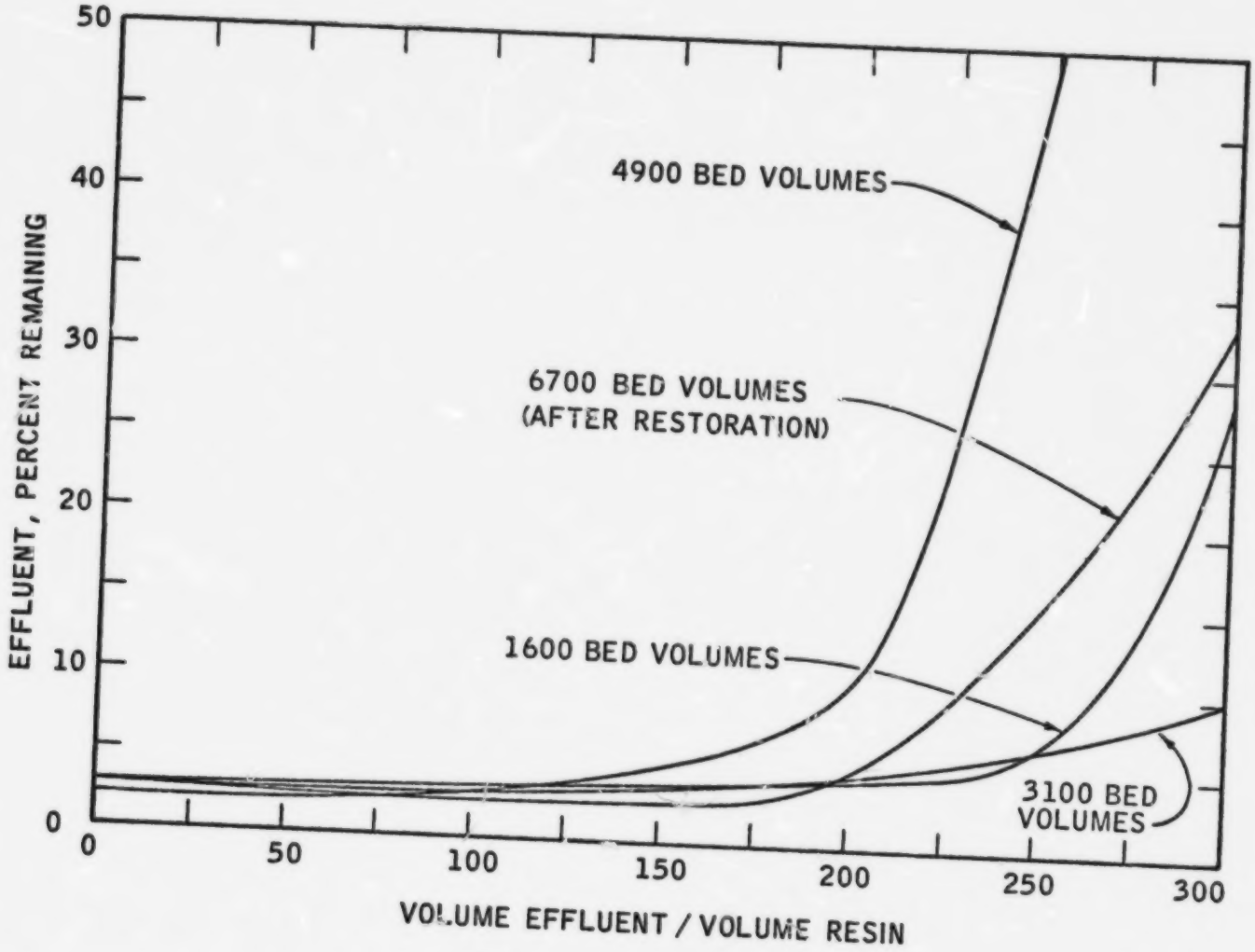


Fig. 4 - Phosphate Removals
Strong-Base Resin

Use of Sea Water as Regenerant

One possible economy would be to use sea water as a source of chlorides for regeneration, rather than sodium chloride. A number of runs to exhaustion were made using A-102D with filtered sea water as a regenerant. Initially, the results were good but they gradually deteriorated. The results of one run, at the conclusion of which 1,940 bed volumes of filtered secondary effluent had been put through the resin, are shown in Fig. 3. Influent characteristics are shown in Table 1. Influent chlorides were high, but it is believed that poor results were due to other reasons.

Removals of organics as measured by COD and color analysis were much the same as those achieved by this resin using sodium chloride as a regenerant. However, results were poor for removals of inorganics, phosphates, nitrates and nitrites, and ABS. Removals were low and breakthrough occurred early. It is thought that low removals were caused by insoluble compounds of calcium and magnesium, notably calcium phosphate which precipitated out in the resin bed and lowered resin efficiency. Since exchange of inorganics was low, the increase in chlorides was low.

Regeneration of the clogged resin with pure sodium chloride solution restored the full efficiency of the resin. Although the use of sea water as a regenerant was not successful, the possibility of using sea water for a portion of the regeneration remains for future investigation.

High Chlorides in Influent

High chloride content in the influent effectively reduced removals--all runs with a chloride content of 200 mg/l or higher were obviously affected. In one run shown in Figure 5, when about 4,000 bed volumes had been passed through the resin, the chloride content was relatively low for the first part of the run (117 mg/l) and high (520 mg/l) for the last part of the run. Influent values are shown in Table 1. The resin was strong-base resin. For the first part of the run, removals proceeded in a normal manner. For the last part, however, the action

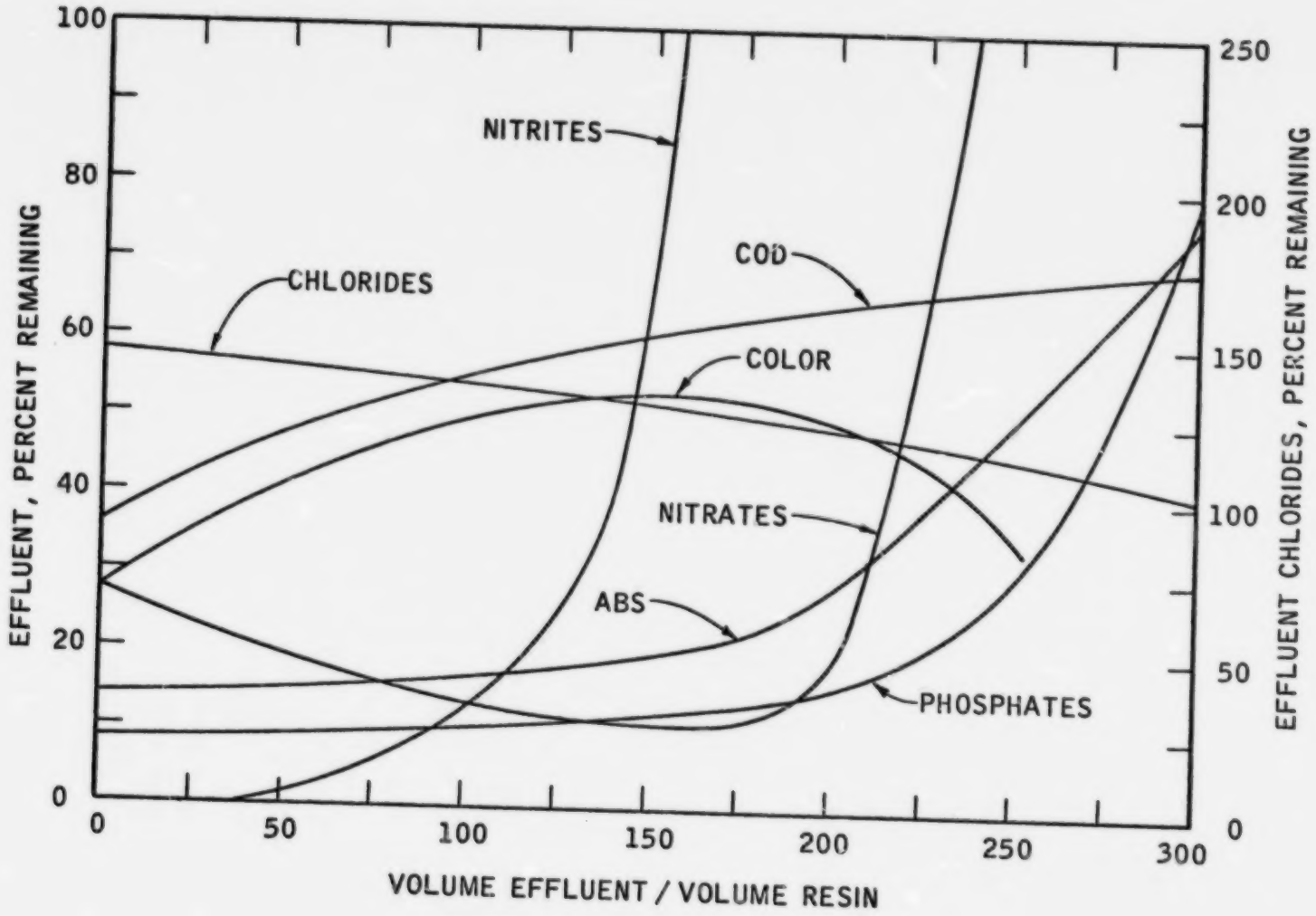


Fig. 3 - Sea Water Regeneration
Strong-Base Resin

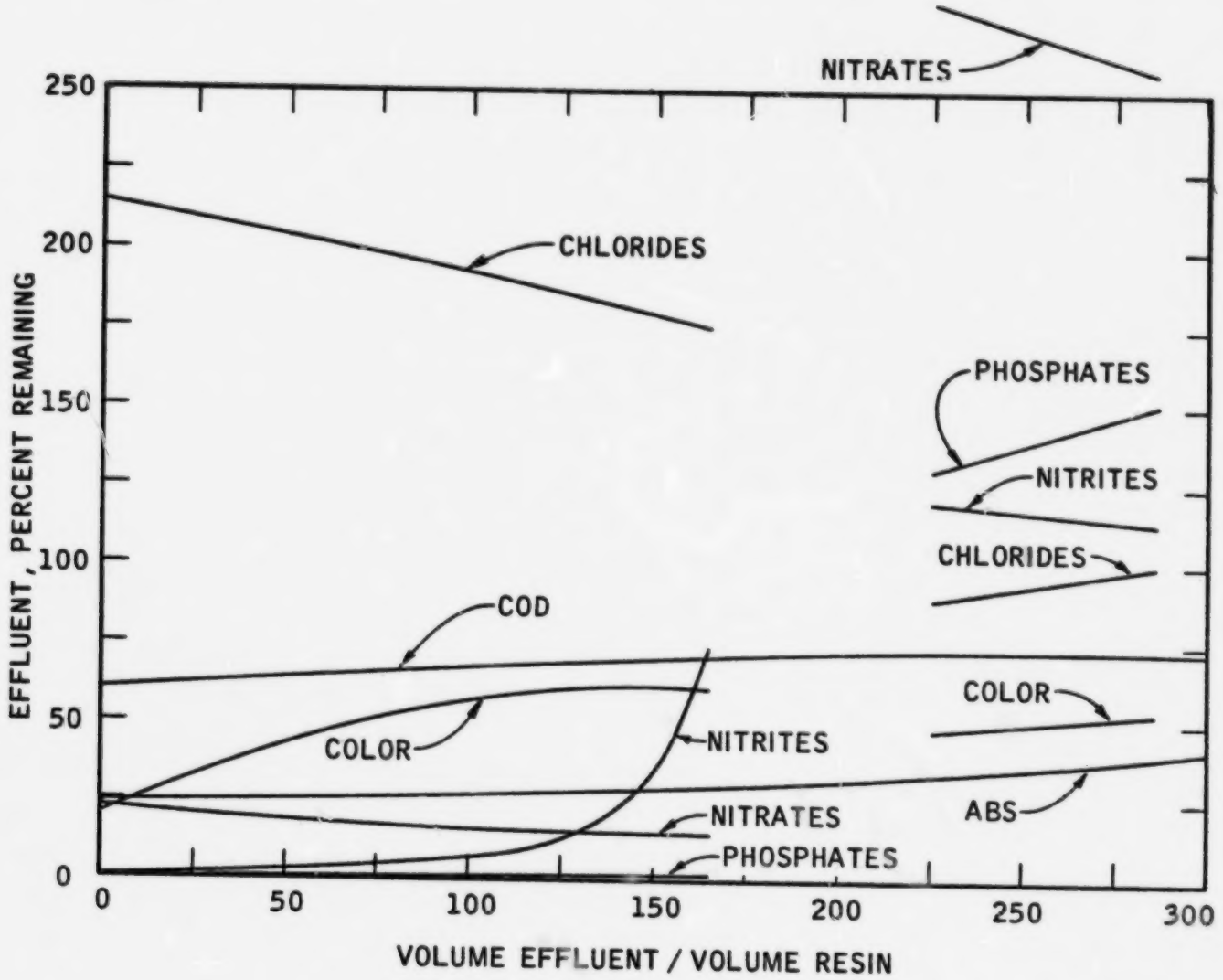


Fig. 5 - High Chlorides in Influent Strong-Base Resin

was completely reversed. Chlorides were removed from solution, and phosphates, nitrates and nitrites were added. High chlorides in the influent can have an extremely adverse effect on removals of inorganics. Removals of organics, however, are not affected.

Use of Unfiltered Effluent

All results previously reported were performed using filtered secondary effluent. To investigate the necessity of filtering the influent to the resin, a number of runs were made using unfiltered secondary effluent. The average results of four runs to exhaustion, at the conclusion of which 1,600 bed volumes had been put through A-102D strong-base resin, are shown in Figure 6. The resin was regenerated with 2 bed volumes of 10 percent sodium chloride prior to each run. Influent values are shown in Table 1.

The results may be compared with Figure 1, showing tests for the same resin and the same amount of influent. Removals of inorganics and ABS were close to those shown in Figure 1, but were slightly inferior. Percentage removals of color and COD were improved but this was, at least in the case of COD, because of filtering action of the resin.

Operating problems were encountered due to the unfiltered influent. It was difficult to maintain the desired flow rate through the resin, and it was also difficult to completely clean the resin by backwash. It is concluded--on the basis of limited laboratory work--that it is desirable to filter the influent, but that no serious harm would result if the filtering were not completely effective. One other possibility would be to remove suspended matter by chemical coagulation and settling before ion exchange. The ion exchange bed in this case would act as a filter to remove any floc carryover.

Dual Bed with Weak-Base Resin

Another possibility of using a weak-base resin involved the use of two beds of A-7 weak-base resin. The first bed is in the acid form. Flow through this bed becomes acidified. Phosphates, for example,

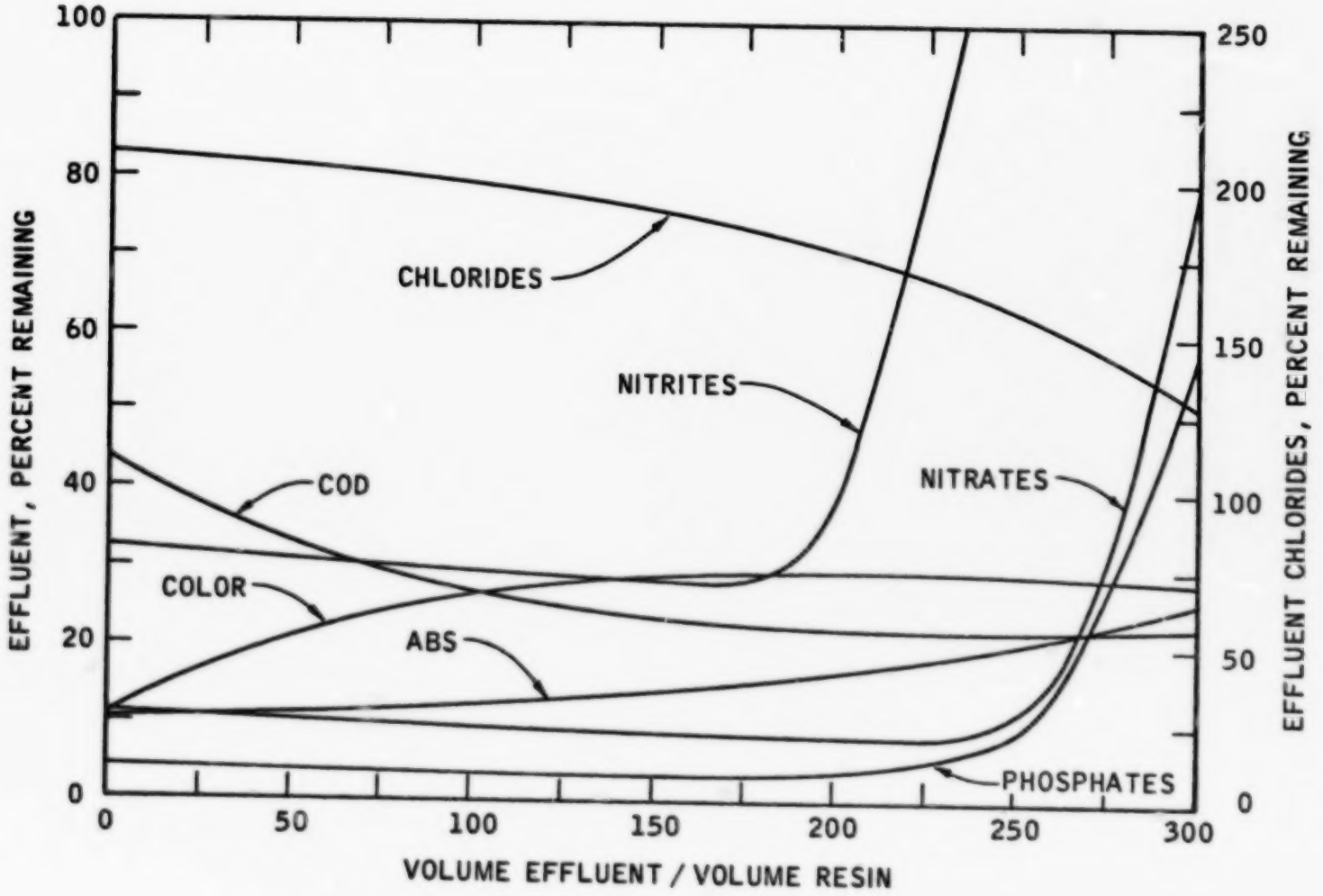


Fig. 6 - Unfiltered Effluent
Strong-Base Resin

come off as phosphoric acid, H_3PO_4, or one of the other phosphorus acids. Chlorides come off as hydrochloric acid. The acids hopefully would be adsorbed on the second bed of resin which is in the hydroxide form. When the second bed was exhausted, it would be in the acid form. It could then be shifted to position No. 1. The original first bed could be regenerated with caustic and shifted to position No. 2. This idea did not work. The effluent from the first bed was apparently not sufficiently acid to be attracted to the second bed. The idea was abandoned.

Ion Balance and Resin Capacity

Ions before and after the ion exchange resin were balanced as a check on analytical procedures and to be sure some important ion was not overlooked. Table 3 includes data from fourteen runs.

TABLE 3

ION BALANCE

		Sample Difference Percent		
	Meq/l	High	Low	Average Diff. %
Influent	10.0			
Sample 1	9.8	+ 8	-7	-2
2	9.9	+ 7	-7	-1
3	10.0	+16	-6	0
4	10.0	+12	-4	0
5	10.2	+15	-8	+2

and shows the average of all anions in Meq/l in the influent and in the five samples taken for each run for all 14 runs for which complete data was available. The largest differences between the influent and effluent for any sample are shown in percent as well as the difference of average for all runs for each sample. For most runs, all values were quite uniform.

The capacity of the strong-base resin for the length of the run

for nine runs to exhaustion ranged from 0.62 Meq/ml (milliequivalents per milliliter) to 1.01 Meq/ml. The lengths of runs were essentially as shown in Figures 1 and 4--runs were carried past phosphate breakthrough, but often were stopped short of total exhaustion. For comparison, the handbook values of theoretical capacity and operating capacity for this resin are 1.4 Meq/ml and 0.8 - 0.85 Meq/ml, respectively.

Waste Disposal

A discussion of water renovation would not be complete without mentioning waste disposal. Waste from ion exchange will consist of backwash water, rinse water, and spent brine, containing small amounts of exchanged ions. Most or all of the backwash water could probably be salvaged by returning it to the influent storage or to a pre-treatment process. Based upon laboratory studies, regenerant would be 2 bed volumes in quantity and rinse water might be as much as 10 bed volumes. From Figures 1 and 4, it appears that each run would amount to about 200 bed volumes. Some economy could be practiced by utilizing the last part of the regenerant for a run for the first part of the regeneration of the subsequent run. In a similar manner the last portion of rinse water for a run could be used for the first part of the rinse for the subsequent run. On this basis the combined quantity of regenerant and rinse water to be disposed of would be about 3 percent of the total water processed.

The ideal waste disposal point would be the ocean or saline surface or underground waters. It probably would not be desirable to discharge wastes into fresh surface or underground waters. In regions where a convenient disposal point is not available, distillation could be an economical answer considering the small quantity of waste and the possibility of utilizing the distilled water produced.

Cost

In order to evaluate the cost of renovating water, some yardstick or base must be used. The City of Palo Alto purchases its water from the City of San Francisco's Hetch Hetchy System at a cost averaging

$65.00 per acre-foot. This is equivalent to 20 cents per 1,000 gallons.

The costs which would be properly charged against a water renovation system would include all treatment costs beyond those of sewage treatment which is normally required in this area. Plant and equipment costs, operational costs, site costs, chemicals, power and waste disposal costs must be included, as well as water storage and transmission facility costs. At the present time only chemical costs can be estimated.

Based on a price for kiln dry salt delivered to Palo Alto at $18.60 per ton when bought in large quantities, a length of run of 200 bed volumes from Figures 1 and 4, and regeneration with 2 bed volumes of 10 percent solution, the cost for sodium chloride required would be 4 cents per 1,000 gallons. The cost includes the use of some of the product as rinse water and the use of the regenerant twice--the last portion of the regenerant of one run to be used for the first portion of the subsequent regeneration. This cost is for the purchase of the regenerant only.

Costs of resin restoration treatment are uncertain at this time because it is not known what treatments will prove necessary or how often they should be applied. Of the two treatments tried, it is more likely--based on meager test data--that the treatment with sodium hydroxide improved the resin performance rather than the methanol and acid treatment. The cost for the chemicals only for the sodium hydroxide treatment would be 0.4 cents per 1,000 gallons. This cost assumes restoration treatment after each 5,500 bed volumes treated, the point at which the restoration treatment was tried in the laboratory, a cost of sodium hydroxide of $56.00 per ton on a dry basis plus freight to Palo Alto, and use of the chemical twice as previously described.

The methanol and acid restoration treatment would be considerably more expensive due to the high cost of methanol. A recovery system for methanol would probably be justified should this treatment prove necessary.

Resin replacement costs cannot be accurately estimated because resin life is unknown. Based upon resin life in other water treatment processes, it is probable that resin replacement costs will be about the

same order of magnitude as the chemical costs previously mentioned--chemical costs for regeneration and restoration treatments.

Continuous Run

Ion exchange studies are continuing but instead of running samples on a batch basis, the influent is being pumped through the column using a sigma motor pump, and sampled automatically. Two identical columns of strong-base resin are being operated with the purpose of studying resin fouling and restoration treatments.

CHEMICAL PRECIPITATION

Chemical precipitation for phosphorus removal was evaluated using conventional jar tests. The coagulant was added to the activated sludge effluent in 1-liter beakers. After an initial mix, coagulation was performed at 30 rpm for 10 minutes and the mixture allowed to settle for one hour.

The following coagulants were tried:

Commercial Alum (Liquid)

Commercial Ferric Sulfate

Puriflcc 501, 502, 601, 602 (Dow Chemical Company)

Phosphate removal data from the last annual report on chemical treatment using liquid alum and ferric sulfate with some additicns are replotted on Figures 8 and 9. These data were gathered using a constant pH for each jar test, and varying the chemical dose of coagulant in the various jars. Each curve represents several runs. Some variation occurs because of differing characteristics of the treated sewage. pH was adjusted using lime.

Color removal from some of the same runs when pH was adjusted to 7.0 is shown in Figure 10.

Additicnal data was gathered using a constant dose of liquid alum for each jar test and varying the pH using sulfuric acid or lime as required. Phosphate and color removals are shown in Figures 11 and 12. Each point represents the average of several runs and, as before some variation can be expected because of differing feed characteristics. Initial phosphate concentration ranged from 5.6 to 11.3 mg/l and averaged 8.4 mg/l as phosphorus.

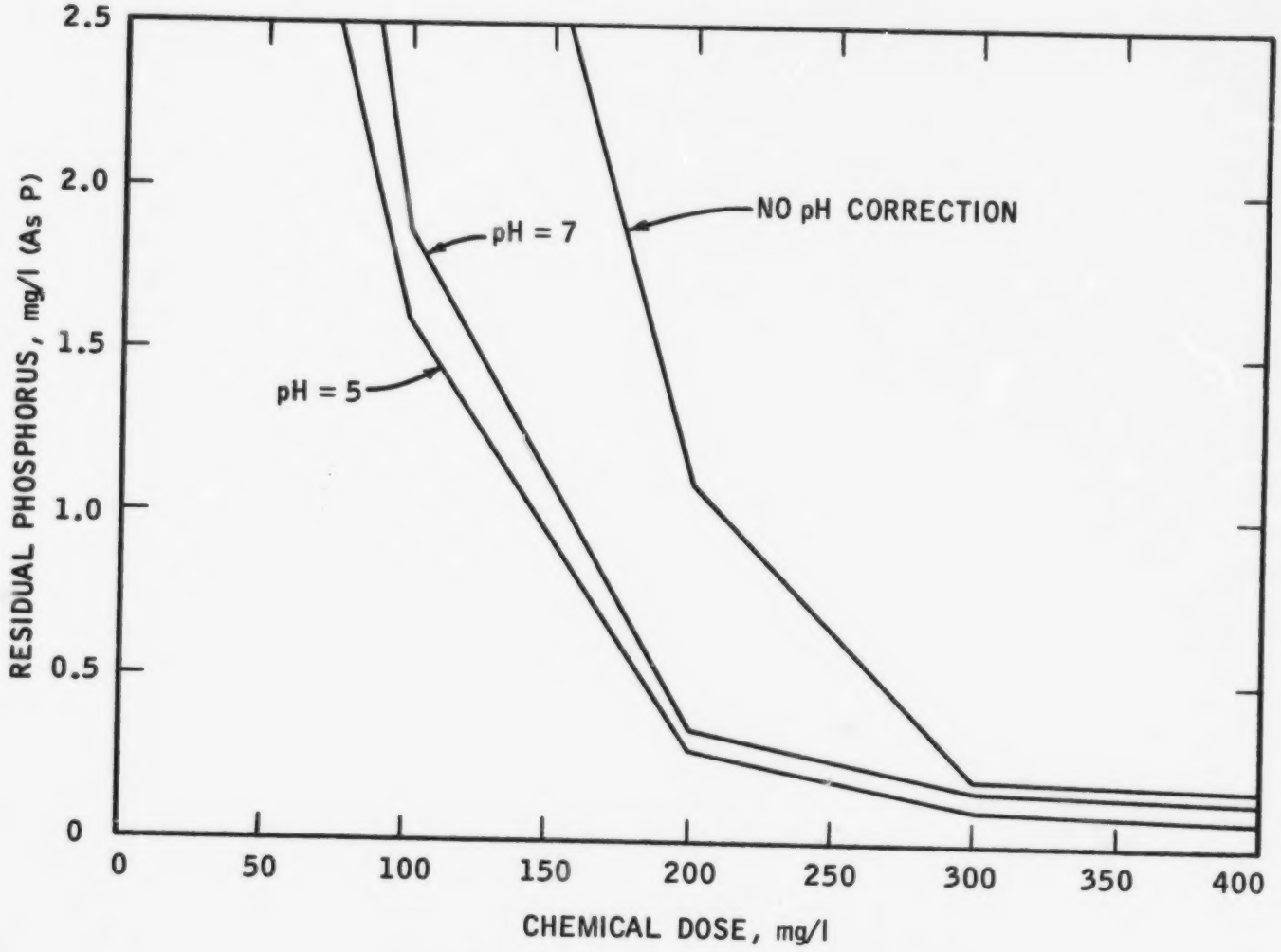


Fig. 8 - Chemical Coagulation with Liquid Alum

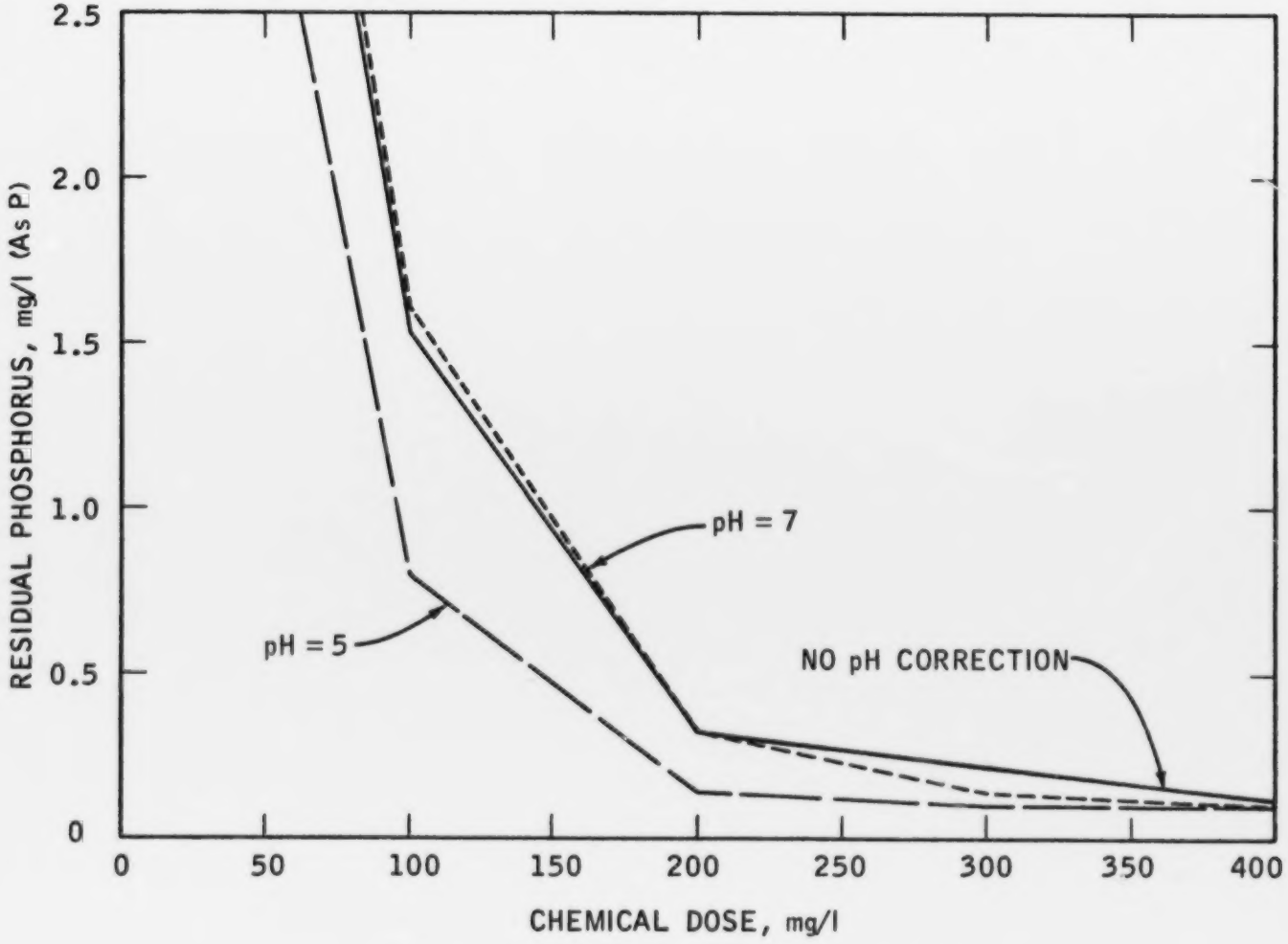


Fig. 9 - Chemical Coagulation with Ferric Sulfate

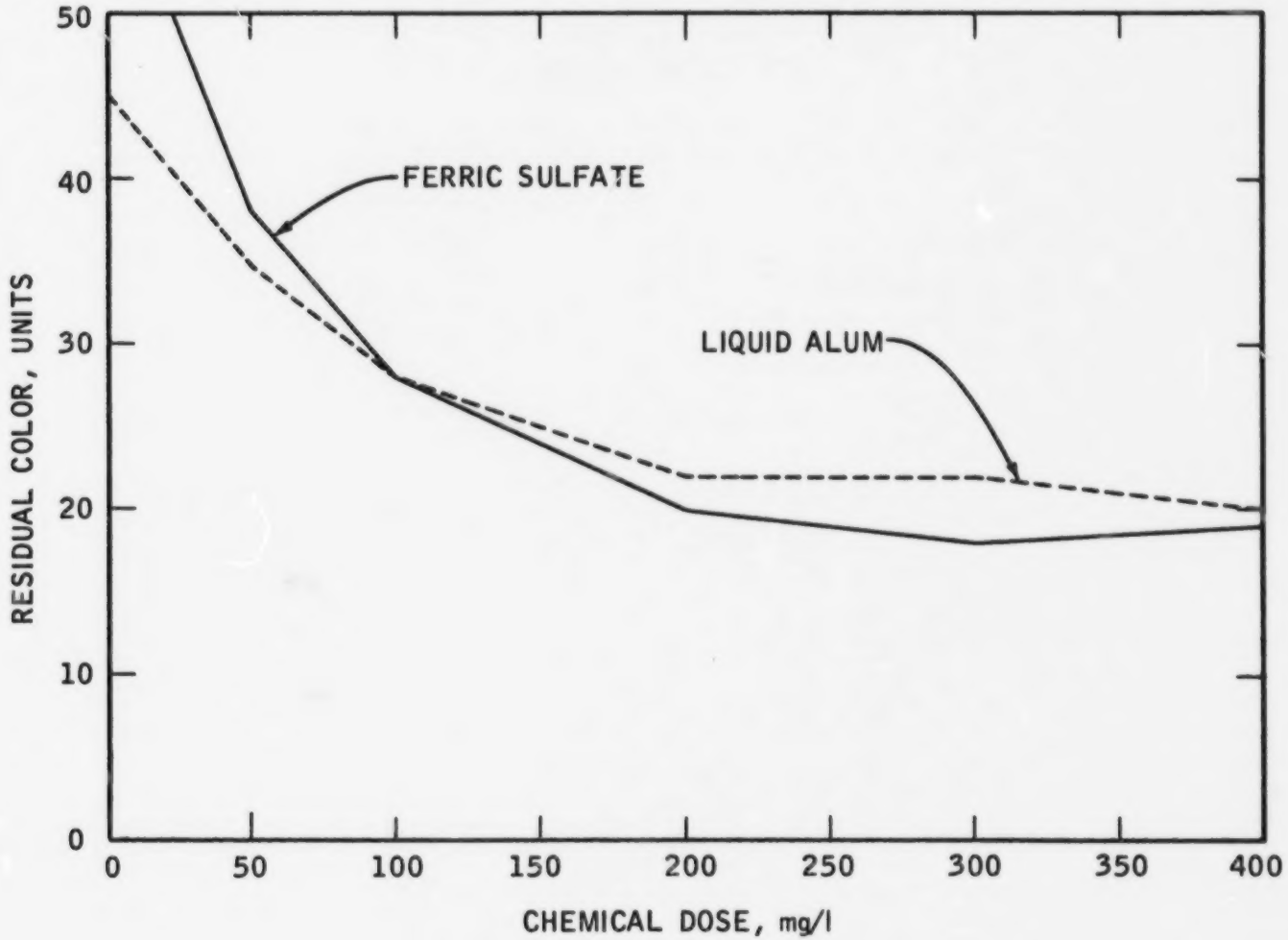


Fig. 10 - Color Removal at pH = 7

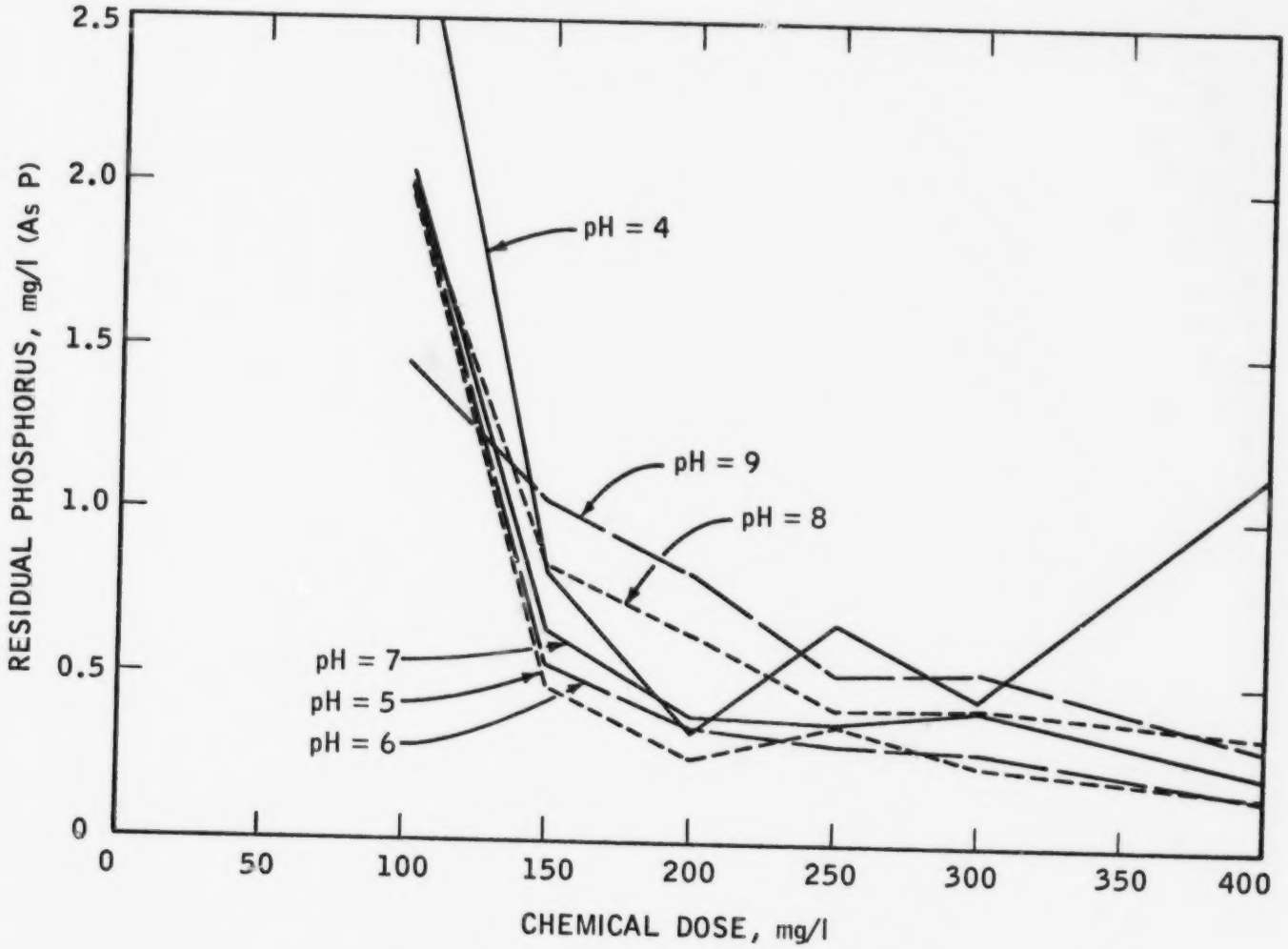


Fig. 11 - Chemical Coagulation with Liquid Alum

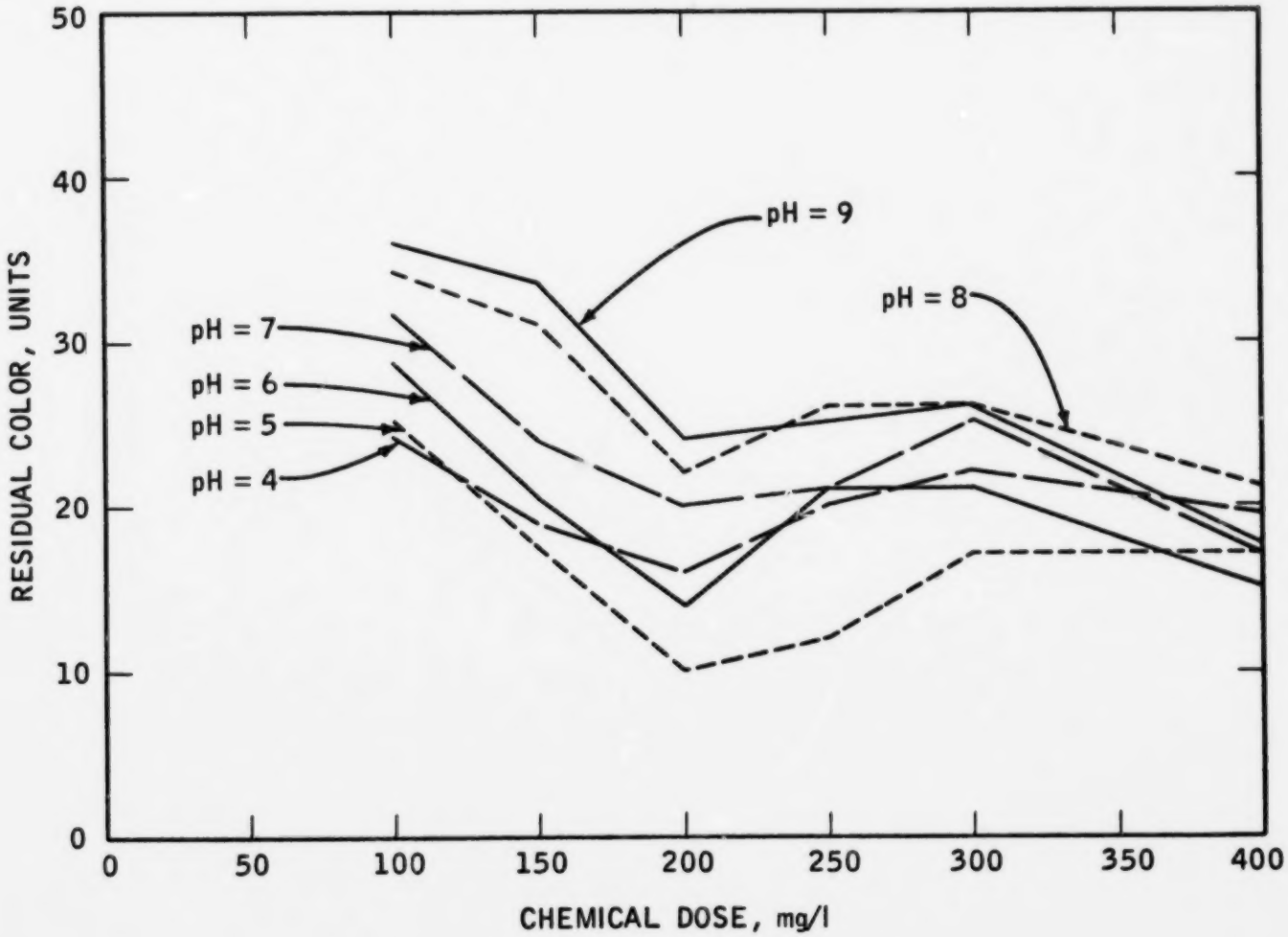


Fig. 12 - Color Removal with Liquid Alum

FOAM FRACTIONATION

Studies with foam fractionation have been continued and have been completed. The same foamer, obtained from California Research Corporation of Richmond, California, was used throughout the study. The foamer volume was 80 ml which resulted in a residence time of 11-1/2 minutes in the foamer.

The effect of the foamer on ABS concentration, COD and on nitrogen content and form was studied. The foamer was operated under two different conditions. In one case, the foam was collected and removed physically from the system. In the second case, the foam was returned to the mixed liquor compartment or recycled.

BOD removal data was also gathered, but because of the low values in the treated sewage and variations caused by taking grab samples, no meaningful data were obtained.

There seems to be little difference between results at the different air flow rates. This leads to the conclusion that all air rates were above the optimum for this foamer size and flow. Different foamer sizes or flow rates were not investigated. Since raw sewage was used in the experiments, the ABS content varied considerably making results for different conditions somewhat difficult to compare.

ABS Removal

ABS removals are shown in Table 4. Each phase represents from 2 to 5 samples collected over a period of weeks, and each represents samples from which foam was either collected or recycled. Phases are segregated by air flow rate. All foamer results are shown including those which were presented in the last annual report except that Phase III, which represents data taken when only half the flow was put through the foamer, is not shown.

Foam Collection. The foamer removed between 45 and 76 percent of the ABS present when foam was collected and reduced the ABS concentration to between 0.63 and 1.0 mg/l. In general, the higher removals

TABLE 4

FOAM FRACTIONATION
ABS Removal

		FOAM COLLECTION						FOAM RECYCLE			
		ABS Concentration mg/l			% Removal			ABS Concentration mg/l			% Removal
Phase	Air Flow ml/min	Raw Sewage	Before Foamer	After Foamer	Mixed Liquor	Foamer	Overall	Raw Sewage	Before Foamer	After Foamer	Overall
I	---	5.3	2.6	1.0	51	62	81				
II	---							3.8	3.2	1.0	74
IV	---							3.1	2.1	0.91	71
V	---	2.8	1.4	0.63	50	53	81				
VI	51	6.3	4.0	0.95	36	76	85				
VII	51							3.7	3.3	1.3	65
VIII	80							4.3	5.4	0.93	78
IX	80	3.9	2.0	0.68	48	66	82				
X	148	5.4	2.3	0.88	57	62	84				
XI	148							4.2	3.9	1.2	71
XII	148	4.1	2.6	1.0	37	62	76				
XIII	235	2.7	1.5	0.83	44	45	69				
XIV	235							4.4	4.6	1.1	75
XV	235	5.2	2.4	0.90	54	62	83				
XVI	235							6.3	6.1	1.6	75
XVII	235	6.5	2.2	0.80	66	64	88				
Average							81				73

resulted when the initial concentration was high. The activated sludge system itself removed from 1.2 to 4.3 mg/l ABS or from 36 to 66 percent of the initial concentration. Here also the highest removals, both in actual concentration and in percentage removal, occurred at the highest initial concentrations. Overall removals are shown also in Table 4 and range from 69 to 88 percent and average 81 percent.

Foam Recycle. When foam was recycled, the ABS concentration in the mixed liquor and effluent naturally was higher. Removals in the foamer were improved, ranging from 56 to 83 percent. The ABS concentration in the effluent was higher, varying from 0.91 to 1.6 mg/l. More ABS was degraded in the activated sludge from 2.2 to 4.7 mg/l, which corresponds to between 65 and 78 percent of the initial concentration, which is also the total removal for the unit when operated on foam recycle.

California Research Corporation developed the foam recycle method which allows the activated sludge to increase degradation of detergents. Their work is presented in a paper by Sharman, Kyriacou and Searle [Ref. 5].

The foam recycle showed promise for increasing the removal of ABS by the activated sludge system. While the concentration of ABS in the treated sewage was higher when using foam recycle and percentage removals were lower, there was no foam to dispose of and removal in the activated sludge was greater. Percentage removal is more meaningful than actual concentration of ABS removed because the latter is greatly influenced by initial concentration.

COD Removal

Other organic material as measured by COD is removed by the foaming process also. Data on COD removal for all tests run on the foamer are shown in Table 5. Data for Phase III is omitted, as before. It is difficult to compare actual COD removal because of differing initial concentration, but based on percentage removal, the foam recycle performed about as well as the foam collection system. With the foam recycle, of course, there would be no foam disposal problem.

TABLE 5

FOAM FRACTIONATION

COD Removal

		FOAM COLLECTION						FOAM RECYCLE			
		COD Concentration mg/l			% Removal			COD Concentration mg/l			% Removal
Phase	Air Flow ml/min	Raw Sewage	Before Foamer	After Foamer	Mixed Liquor	Foamer	Overall	Raw Sewage	Before Foamer	After Foamer	Overall
I	---	527	88	66	83	25	87				
II	---							559	107	67	88
IV	---							458	81	69	85
V	---	183	73	41	60	44	78				
VI	51	410	110	104	73	5	74				
VII	51							341	74	38	89
VIII	80										
IX	80	544	68	57	87	16	89	416	69		91
X	148	556	84	43	85	49	92				
XI	148										
XII	148	585	76	58	87	24	90	524	87	41	92
XIII	235	440	52	46	88	12	89				
XIV	235										
XV	235	603	56	42	91	25	93	508	85	48	91
XVI	235										
XVII	235	555	60	43	89	28	92	573	68	45	92
Average							87				90

Comparison of data for ABS removal and COD removal shows that the additional ABS removed in the activated sludge system because of the foam recycle accounts for only a portion of the additional COD removal because of the foam recycle.

Nitrogen Removal

A rather complete nitrogen balance was kept for the entire period of operation of the foamer. Tests for organic nitrogen, ammonia, nitrates, and nitrites, both before and after the foamer were performed on a weekly basis. Samples were somewhat variable because they were merely grab samples and also because of changes in the activated sludge system. Nitrogen was removed periodically by the denitrification chamber and the form was variable depending on the operation of the activated sludge system. The effluent was alternately higly nitrified and poorly nitrified, but was seldom only partly nitrified.

The foamer operation functioned to remove a small quantity of nitrogen from the system. The actual method of removal is unknown. The average removal of all samples tested was 1.6 mg/l or 6 percent. There was a much larger increase in nitrification than there was a reduction of nitrogen, as shown by Table 6. A well-nitrified effluent for the purposes of this table is defined as one in which the nitrate concentration exceeds the ammonia concentration.

TABLE 6

NITROGEN CONCENTRATION mg/l as N

	Before Foamer	After Foamer
Ammonia		
Well nitrified effluent	1.2	0.2
Not well nitrified effluent	17.8	9.9
Nitrate		
Well nitrified effluent	17.3	18.4
Not well nitrified effluent	5.0	12.4

DENITRIFICATION STUDIES

Certain bacteria are able to utilize oxygen obtained from nitrates and nitrites in the absence of dissolved oxygen. In order to take advantage of this, bacteria in the mixed liquor of the activated sludge are allowed to come in contact with raw sewage in the absence of air in a separate chamber of the aeration compartment. If well nitrified activated sludge is available, denitrifying bacteria will utilize oxygen from the nitrates and nitrites and liberate nitrogen as a gas.

During the early part of this study, a denitrification compartment was made by putting a movable baffle into the mixed liquor compartment of the activated sludge unit. Some difficulties were encountered with mixing, but these presumably were solved after the fabrication of a 20 rpm mixer. Initially, flow was introduced into the denitrification compartment by allowing mixed liquor to flow over a weir in the baffle when the mixed liquor was aerated, as was done by Ludzack and Ettinger [Ref. 6].

There was a notable lack of success in denitrification when the denitrification chamber was taken as part of the mixed liquor compartment for two principal reasons: first, the flow, compartment sizes and the operation of the activated sludge unit were all such that the load ratio was relatively high, resulting in poor nitrification. Load ratio is defined as pounds of BOD per day per pound of mixed liquor volatile solids. Secondly, the denitrification compartment was generally too small to provide a long enough detention time for denitrification to take place. These difficulties were overcome by providing a separate denitrification chamber.

The flow into the denitrification chamber was found to be exceedingly difficult to control and almost impossible to measure. These problems were overcome by pumping the return sludge from the settling basin to a denitrification tank from which it flowed by gravity to the mixed liquor compartment. This scheme offered the additional advantage of introducing sludge which was already partially starved for oxygen, by reason of its passage through the settling tank, into the denitrification chamber.

The separate denitrification chamber is shown in Figure 13. The volume in the denitrification chamber could be adjusted by raising or lowering the container. The 20 rpm mixer was installed in the denitrification compartment. On May 12, 1964, the speed of the mixer was increased to 40 rpm. Results of all tests after the separate denitrification chamber was installed are shown in Table 7.

As can be seen from Table 7, the only sustained period of good denitrification was the period from May 21, 1964, to June 12, 1964. During this period the nitrification was essentially complete. The reason for this probably was the low load ratio, although other periods of complete nitrification occurred when the load ratio was not low. This period also had a high detention time in the denitrification compartment which is apparently necessary for the denitrification process. The lack of success early in the program was probably due to the lack of a sustained period with both a low load ratio and a long detention time. Sludge bulking problems made it difficult to keep a high mixed liquor solids content with attendant low load rates.

There were other difficulties also. Due to the small size of the settling chamber and the lack of a mechanical collector or scraping mechanism, sludge would build up on the sides of the settling chamber, particularly at night, and remain there for long periods of time. Early in the operation the denitrification seemed to have an adverse effect on the nitrification process.

Due to the many different processes operated and the number of tests performed, it was not possible to do the number of tests and give the unit enough attention to exercise a close control on the operation.

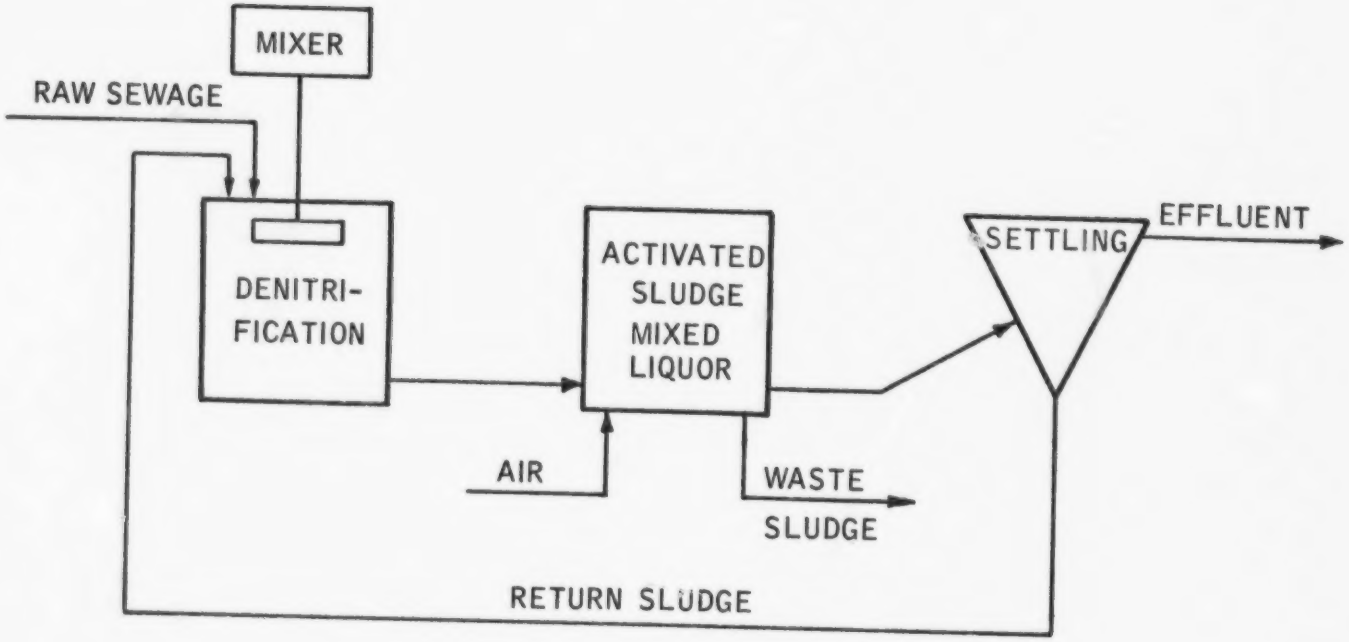


Fig. 13 - Denitrification Arrangement

TABLE 7

DENITRIFICATION SUMMARY

Date	Nitrogen as N: Raw Sewage Total	Activated Sludge Effluent: Organic	NH_3	NO_3	NO_2	Total	% Red.	Dentr. Compt. Size/ml	Detent. Time min.	Load Ratio
1963										
10/21								500	8	
10/24										0.73
10/25	52.6	3.9	1.4	6.5	1.7	13.5	74	500		
10/31										0.50
11/1	34.9	4.2	1.4	14.2	1.2	21.0	40	500		
11/7										0.45
11/8	48.6	2.5	0	32.4	0.5	35.4	27	500		
11/14										0.63
11/15	54.0	2.8	0	24.5	0.3	27.6	49	500		
11/18								700	11	
11/21										0.57
11/22	54.2	3.5	0	24.6	1.1	29.2	48	700		
11/25								1000	15	
11/27										0.44
11/29	55.7	3.6	0	31.7	0.2	35.5	36	1000		
12/5								1330	20	0.36
12/6	58.0	2.0	0.8	20.8	1.3	24.9	57	1330		
12/12										0.33
12/13	56.4	11.2	18.2	7.7	0.4	37.5	34	1550		
12/16								1600	27	
12/19										0.57
12/20		4.2	0					1600		

TABLE 7 (Continued)

Date	Nitrogen as N: Raw Sewage Total	Activated Sludge Effluent: Organic	NH_3	NO_3	NO_2	Total	% Red.	Dentr. Compt. Size/ml	Detent. Time min.	Load Ratio
1964										
1/2										0.38
1/3	49.5	4.6	0	10.4	0.3	15.3	69	1600		
1/9										0.54
1/10	56.4	3.9	0	11.1	0.3	15.3	73	1600		
1/16										0.35
1/17				28.7	0.2			1600		
1/23										0.25
1/24	41.9	0.6	0	24.9	0.2	25.7	39	1600		
1/30										0.39
1/31	57.0	3.4	0.7	29.2	0.7	34.0	40	1600	25	
2/5								1600	25	
2/6										0.50
2/7	53.1	2.7	0.4	33.1	0.1	36.3	32	1600		
2/13										0.25
2/14	52.5	2.3	1.1	4.6	0.3	8.3	84	1600		
2/18								1600	42	
2/20										0.38
2/21	59.3	7.3	24.4	2.3	0.3	34.3	42	1600		
2/28	43.2	6.1	15.3	0.9	0.2	22.5	48	1600		
3/4										0.20
3/6	47.7	2.9	19.3	1.1	0.1	23.4	51	1600		
3/12								1600	33	0.29
3/13	43.7	6.2	20.6	0.8	0	27.7	37	1600		
3/19										0.60
3/20	53.1	3.8	15.0	9.8	0.2	28.8	46	1600		
3/25								1600	30	

TABLE 7 (Continued)

Date	Nitrogen as N: Raw Sewage Total	Activated Sludge Effluent: Organic	NH_3	NO_3	NO_2	Total	% Red.	Dentr. Compt. Size/ml	Detent. Time min.	Load Ratio
1964										
3/26										
3/27	56.0	3.9	2.0	18.1	1.1	25.1	55			0.36
3/31								1600		
4/2								1600	33	
4/3	52.1	2.9	0.6	24.9	0.3	28.7	45			0.49
4/10								1600		
4/13										0.28
4/17	53.0	3.2	1.4	19.5	0.2	24.3	54	1800	40	
4/24	61.8	1.7	12.0	9.8	0.2	23.7	62	1800		
4/28								1800		
4/29								1800	44	
5/4	42.5	6.6	12.9	2.8	0	22.3	47			0.45
5/6								1800		
5/7								1800	40	
5/13	40.4	0	25.9	1.3	0	31.3	23			0.48
5/14								1800		
5/21	46.8	2.9	0	7.7	0.1	10.7	77			0.47
5/25								1800		
5/28								1800	55	
5/29	44.0	4.6	0	6.1	0	10.7	76			0.29
6/1								1800		
6/4								1800	47	
6/8	41.6	2.5	0	7.1	0	9.6	77	1800	55	0.21
6/11								1800	69	
6/12	31.7	4.3	0.3	5.7	0	10.3	68	1800	78	
6/13								1800		
6/15								1800	85	
										0.24

ACTIVATED CARBON STUDIES

A number of runs using an activated carbon, type SGL as supplied by the Pittsburg Chemical Company, were made as a comparison with removals by ion exchange. The carbon was contained in a 50 ml burette and had a column length of 15 inches. Flow rate varied between 0.4 and 16.2 bed volumes per hour, but was usually between 5 and 15 bed volumes/hour. The influent to the unit was sewage treated with activated sludge and filtered. The total flow for all runs was 2,990 bed volumes.

Results are shown in Table 8. Removals of COD and color were somewhat better than the strong-base ion exchange resin, but ABS removal was less. As would be expected, there was no removal of inorganics.

TABLE 8

ACTIVATED CARBON SUMMARY

	ABS		COLOR		COD	
1963	Inf.	Eff.	Inf.	Eff.	Inf.	Eff.
7/23	1.45	0.25	>50	0	40	6
8/30			>50	0	35	6
9/10	1.85	0.25	>50	0	39	14
9/12	1.05	0.25	>50	0		
9/18	1.4	0.1	63	14	37	16
9/19			75	13	37	10
9/25	0.9	0.65	75	20	43	15
10/1	1.1	0.2	64	13	41	19
10/9			65	8	21	18
10/11	1.0	0.12	65	13	21	21
10/29	0.85	0.04	45	8		
11/5	0.95	0.25	43	8	34	36
11/6	0.95	0.25	43	3		
11/13	0.72	0.5	24	5	30	18
11/20	1.25	0.25			35	16
1964						
1/6			58	4		
Average	1.12	0.26	56.4	9.9	34.4	16.2

CHEMICAL COAGULATION BEFORE ACTIVATED SLUDGE

A scheme was proposed where chemical treatment would take place before activated sludge. If chemical treatment would be practiced in any event for phosphate removal, the possibility exists of removing most of the phosphates and a great deal of the organic material by chemical means. The activated sludge treatment would then follow and would strip most of the remaining nutrients as well as organic material from the sewage.

Several runs were made using coagulation with 100 to 200 mg/l liquid alum before activated sludge. Effluent from the activated sludge process was very turbid and there was no removal of nitrogen or phosphorus. Further efforts were abandoned.

LAKE LAGUNITA

The original report upon which the project was based concerned the reclamation of reusable water from sewage for the purpose of putting it into Lake Lagunita on the Stanford campus. One of the prime objectives of the project has been the removal of nutrients from water in order to prevent the growth of algae and other organisms in the water.

The lake under present conditions is filled with water diverted from nearby San Francisquito Creek. In dry years, the lake may not be filled at all. In other years it is filled when water is available, and drained late in the year when the water level becomes low.

The lake supports a dense growth of aquatic weeds. Weeds grow both around the edge and up from the bottom in the middle of the lake. There are always algae in the water also, but the lake water is usually quite clear and no nuisance blooms have been observed. One reason why nuisance blooms have not occurred may be that nutrients were taken out of the water by the plant growth.

In order to have some measure of the levels to which nutrients should be removed or at least to compare the quality of renovated water with existing supplies, occasional samples of lake water were taken and analyzed. Table 9 shows results of tests run and the condition of the lake at sampling.

TABLE 9

LAKE LAGUNITA

Date	Condition	PHOSPHATES			NITROGEN					Hardness	Color	Sulfates	ABS	COD	Chlorides	Alkalinity
		Soluble	Organic	Total	Organic	NH_3	NO_3	NO_2	Total							
1963																
1-22	Nearly filled			0.33												
2-25				0.10												
3-21					0.84		0.6									
3-29		0.13	0.10	0.23	0.8		0.32	0.03	1.1				0.3		25	
4-4		0.05												19		
4-4		0.07	0	0.07												
4-11		0.02	0.01	0.03										8		
4-19		0.08	0	0.08												
4-23		0.05	0	0.05									0.08	8		
5-10				0.05												
5-14		0.03	0	0.03											27	
5-24				0.10												
5-28				0.03									0.07		28	
5-28				0.04												
6-7		0.03	0.01	0.04										18		
6-26	Down 3'				2.2	0	0.07	0.003	2.3				0.05	10	33	
7-12	6'	0.02	0.06	0.08												
7-19	7'	0.09	0.04	0.13												
7-22	Down 8'				0.56	0	0.08	0	0.64							
12-7	Started filling recently	0.20	0	0.20			0.07	0.005		137		140			51	200
1964																
1-24	1/3 full	0.19	0.11	0.30	1.1	0.3	0.57	0.01	2.0		>70	76			34	142
2-7	Down 3'	0.09	0.06	0.15	1.5	0	0.63	0.003	2.1	234	20	46			33	143
2-20	" "	0.07	0.05	0.12			0.57	0.54			9	76			37	155
3-6	" "	0.05	0	0.05			0.66	0.01			7	101			39	153
3-13	" "			0.16	0.56	0.34	0.15	0.07	1.12		7	102			39	160
3-27	Down 2'			0.03			0.19	0.01			7	108	0.07	14	38	157
5-1				0.12	1.7	1.3	0.49	0	3.5						44	
5-21				0.12	0.8	0	0.40	0.002	1.2						45	
6-8	Down 6'			0.09	0.42	0.42	0.07	0.005	0.92						41	

TABLE 9

LAKE LAGUNITA

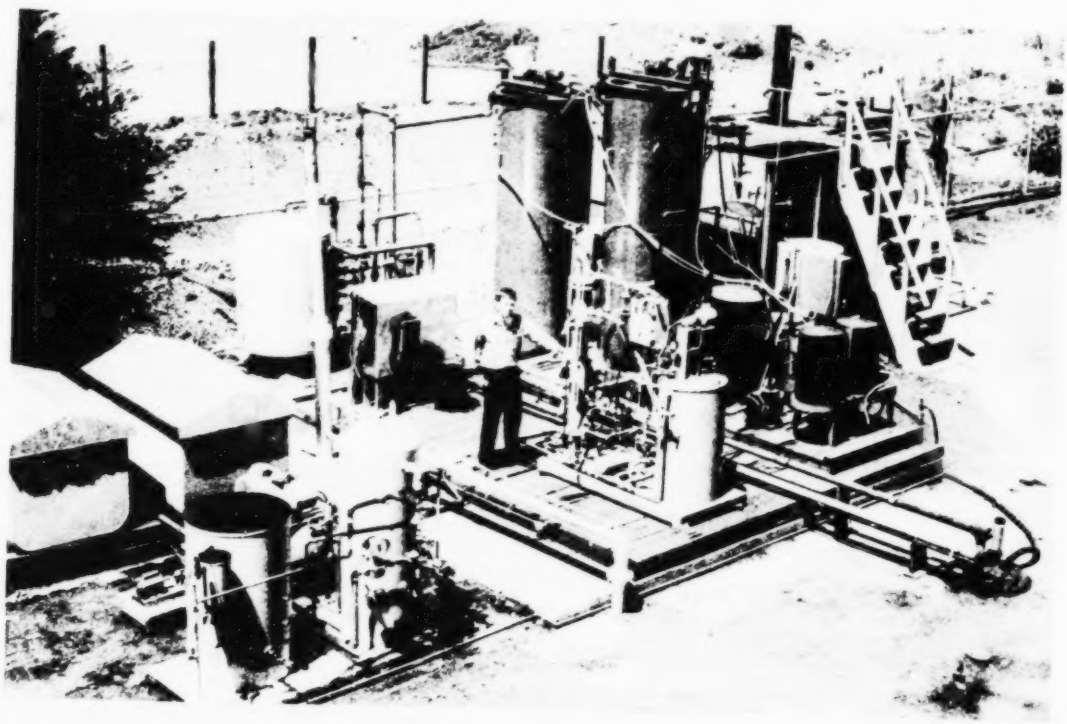
Date	Condition	PHOSPHATES			NITROGEN					Hardness	Color	Sulfates	ABS	COD	Chlorides	Alkalinity
		Soluble	Organic	Total	Organic	NH_3	NO_3	NO_2	Total							
1963																
1-22	Nearly filled			0.33												
2-25				0.10												
3-21					0.84		0.6									
3-29		0.13	0.10	0.23	0.8		0.32	0.03	1.1				0.3		25	
4-4		0.05												19		
4-4		0.07	0	0.07												
4-11		0.02	0.01	0.03										8		
4-19		0.08	0	0.08												
4-23		0.05	0	0.05									0.08	8		
5-10				0.05												
5-14		0.03	0	0.03											27	
5-24				0.10												
5-28				0.03									0.07		28	
5-28				0.04												
6-7		0.03	0.01	0.04										18		
6-26	Down 3'				2.2	0	0.07	0.003	2.3				0.05	10	33	
7-12	6'	0.02	0.06	0.08												
7-19	7'	0.09	0.04	0.13												
7-22	Down 8'				0.56	0	0.08	0	0.64							
12-7	Started filling recently	0.20	0	0.20			0.07	0.005		337		140			51	200
1964																
1-24	1/3 full	0.19	0.11	0.30	1.1	0.3	0.57	0.01	2.0		>70	76			34	142
2-7	Down 3'	0.09	0.06	0.15	1.5	0	0.63	0.003	2.1	234	20	46			33	143
2-20	" "	0.07	0.05	0.12			0.57	0.54			9	76			37	155
3-6	" "	0.05	0	0.05			0.66	0.01			7	101			39	153
3-13	" "			0.16	0.56	0.34	0.15	0.07	1.12		7	102			39	160
3-27	Down 2'			0.03			0.19	0.01			7	108	0.07	14	38	157
5-1				0.12	1.7	1.3	0.49	0	3.5						44	
5-21				0.12	0.8	0	0.40	0.002	1.2						45	
6-8	Down 6'			0.09	0.42	0.42	0.07	0.005	0.92						41	

PILOT PLANT PROGRAM

Phase 2 of the project, the Pilot Plant Program, is now well under way. All equipment is now on the job and most has been operated. Although actual gathering of data has not begun, adjustments in the equipment have been made.

The larger scale pilot plant equipment will afford a better opportunity for a demonstration to the public. Removal of organic material from water will be of interest, of course, but the principal effort will be expended in an effort to remove the nutrients, nitrogen and phosphorus, from the water. The effectiveness of the treatment to prevent the growth of algae will be observed in the detention pond.

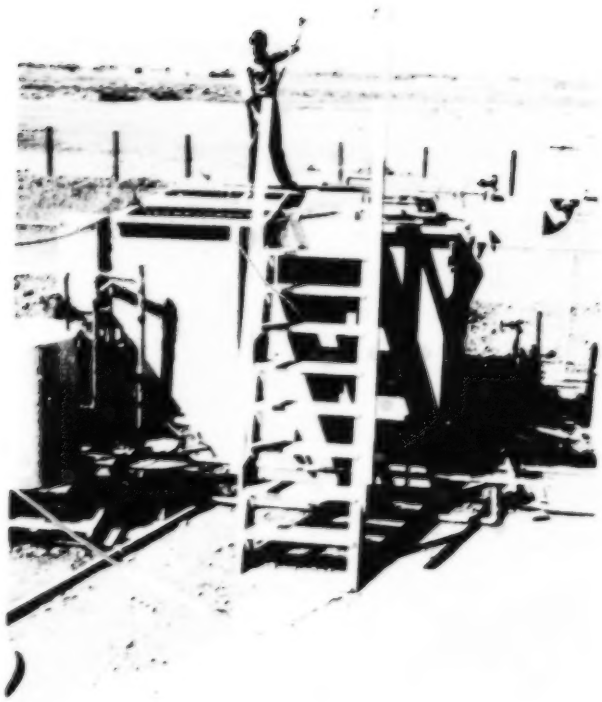
The removal of bacteria and virus by the various units of equipment can also be studied.



PILOT PLANT

ACTIVATED SLUDGE SEWAGE TREATMENT PLANT

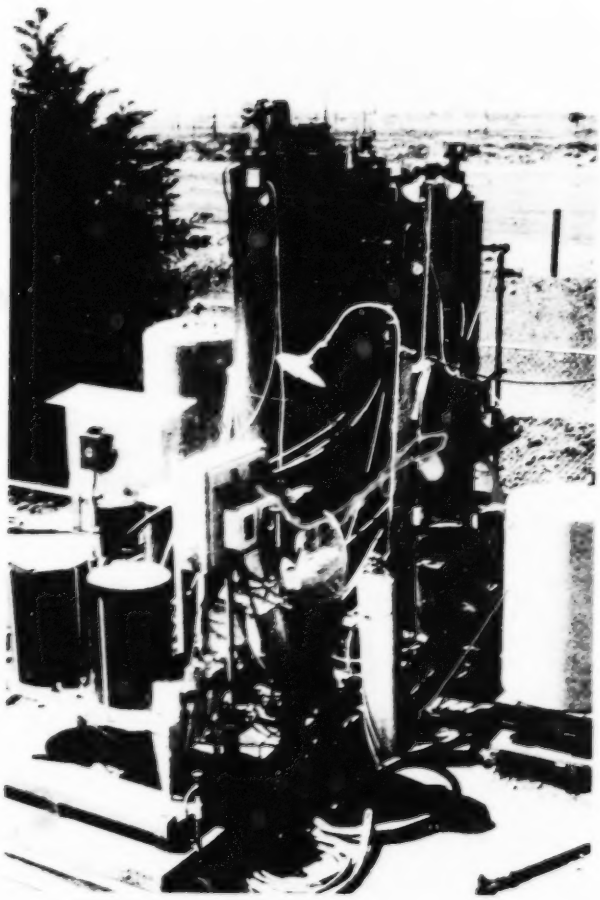
The 10 gpm activated sludge unit has been provided by the Chicago Pump Co., Hydrodynamics Division, FMC Corporation. An existing unit was provided initially early in 1963 and operated by Chicago Pump Company for about four months. This unit is the "Rapid Bloc," a new development by this company which utilizes a gravity sludge return. Chicago Pump Company in September, 1963, replaced this unit with a new unit which is their standard model. The Company operated the united briefly in September, and it was started up again in late January, 1964, as the first unit of the pilot plant. Good operation was not achieved and in early March, 1964, a Chicago Pump Company representative came back and made some modifications in the unit. Late in March, a switch was made in feed to the activated sludge unit from raw sewage to settled sewage. Start-up problems were encountered as might be expected with new equipment, new process, and inexperienced operators. Operation was gradually improved until early June when an excellent effluent was produced which has remained satisfactory since that time.



ACTIVATED SLUDGE PLANT

CHEMICAL TREATMENT UNIT

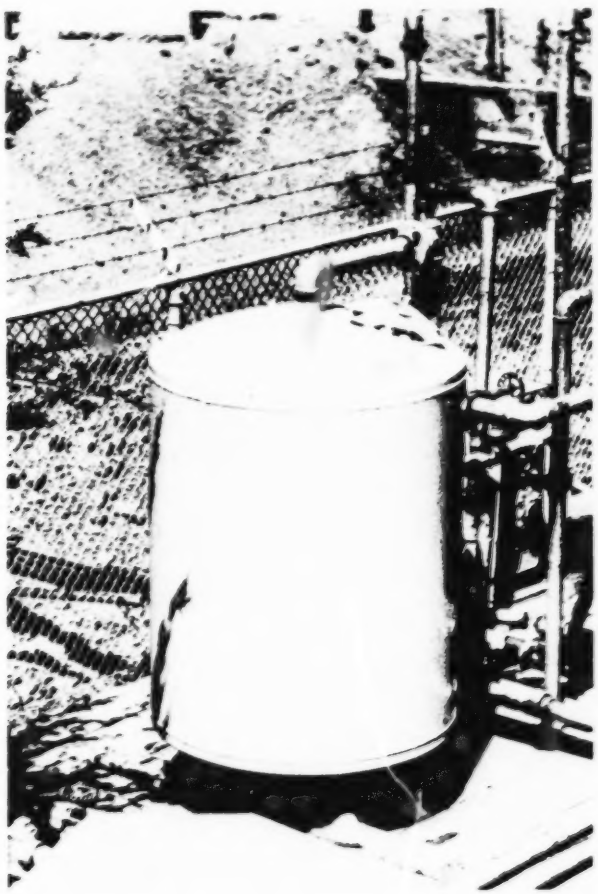
The chemical treatment unit has been provided by Infilco, Division of Fuller Company, from Tucson, Arizona. It was started up in late May, 1961, and has been operated for brief periods since that time. Certain adjustments have been made in the equipment and some of the influent and effluent piping has been rearranged. No meaningful data has been gathered to date, but familiarity with the equipment has been obtained.



CHEMICAL TREATMENT UNIT

SAND FILTER

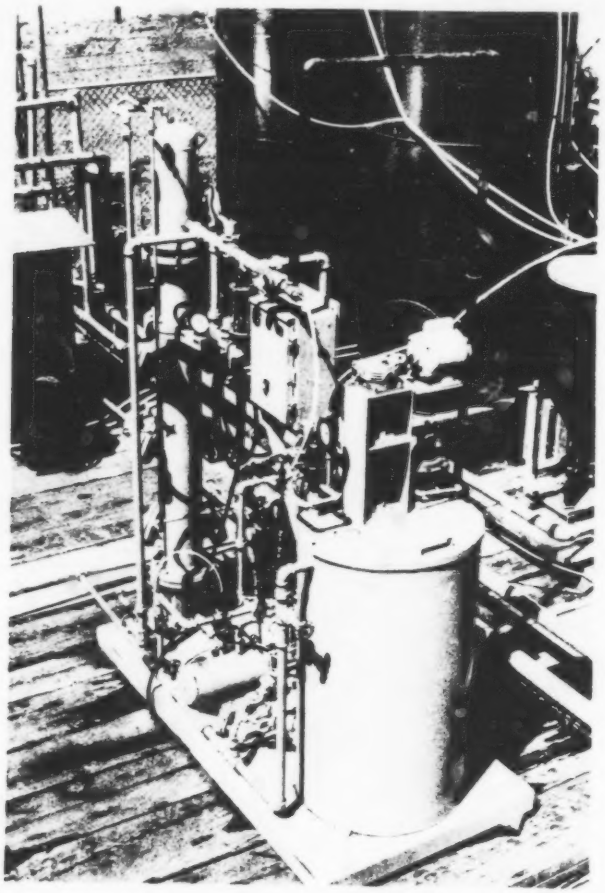
The sand filter has been provided by Infilco. The equipment is in place and has been operated.



SAND FILTER

DIATOMACEOUS EARTH FILTER

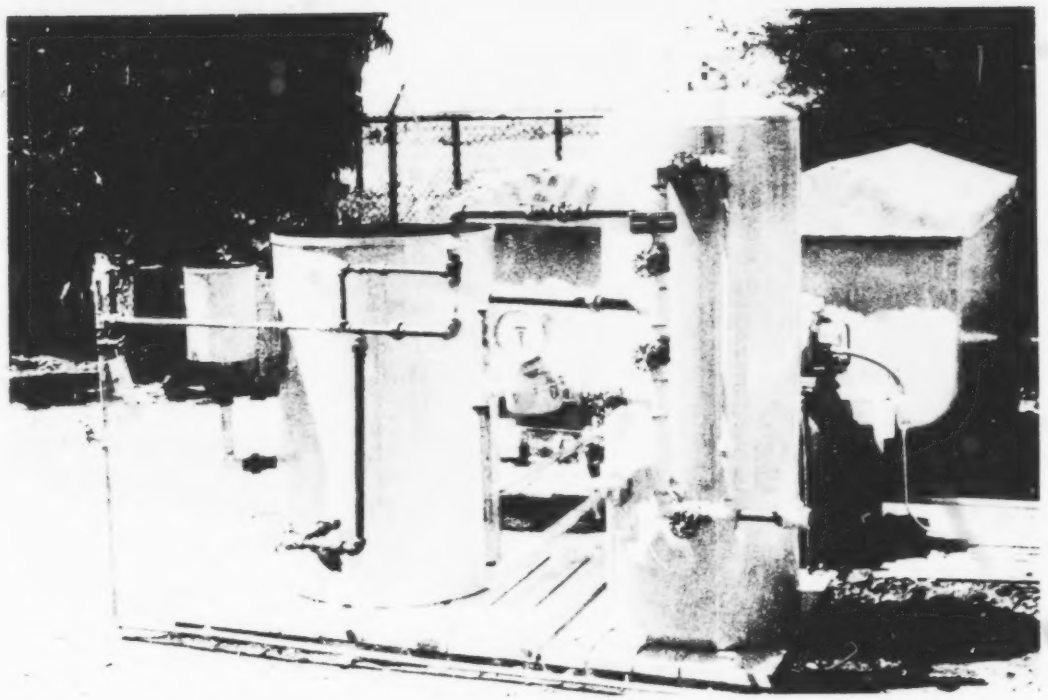
The diatomaceous earth filter has been provided by the DeLaval Turbine, Inc., Filtration Systems Division, from Millbrae, California. The unit was first started up in early April, 1964, and operated occasionally since that time. It has continued to produce an excellent quality of water even when only a partially treated sewage was available as influent. Extensive testing procedures and continuous operation will await the complete installation of the ion exchange unit.



DIATOMACEOUS EARTH FILTER

ION EXCHANGE UNIT

The ion exchange unit also has been provided by Infilco. It is on the job and the installation is substantially complete.



ION EXCHANGE UNIT

POND

The last unit will be a small pond. The principal uses of the pond will be to demonstrate the quality of the effluent produced as a test for prevention of the growth of algae by nutrient removal. Another use would be to test for any treatment received, such as the removal of bacteria and virus through storage.

The pond has been constructed, fenced, and a weir has been put in place to measure flow. A pipe to carry away the effluent has been constructed and the pond will shortly be lined with a polyethylene cloth to prevent possible leaching of nitrogen and phosphorus from the organic soil beneath.

POND

DEMONSTRATION PLAN

The demonstration plan as presented in the first progress report has been altered as follows:

Flowsheet 1	a. activated sludge b. chemical coagulation c. sand filtration d. pond
Flowsheet 2	a. activated sludge b. diatomaceous earth filtration c. ion exchange d. pond

Omitted from Flowsheet 1 as presented in the last annual report are denitrification, foam fractionation, and chlorination. An attempt was made to obtain a suitable denitrification tank at no cost, but this was unsuccessful. Based on laboratory studies, the denitrification process is difficult to operate, at best, and even if successfully operated, nitrogen removal is probably not high enough for many purposes. Lack of time and funds are also reasons for the deletion of this unit. Foam fractionation was eliminated because, in addition to lack of time and funds, another institution in this area is doing studies with foam fractionation at the same scale as we are using in our pilot plant. Chlorination was not thought necessary for demonstration purposes.

pH adjustment was deleted from Flowsheet 2 because this was not necessary if a chloride cycle ion exchange is employed. Chlorination was, again, not necessary for a demonstration project.

PROFESSIONAL STAFF

1. Project Director -- Dr. Rolf Eliassen

   Professor of Civil Engineering, Stanford University.

   Professor Eliassen has been with the project since its inception and has spent about 10 percent of his time on the project. Biographical data was included in the original Application.

2. Dr. Perry L. McCarty

   Associate Professor of Civil Engineering, Stanford University.

   Professor McCarty has been with the project since its inception and has spent about 10 percent of his time on the project. Biographical data was included in the original Application.

3. Bruce M. Wyckoff

   Research Engineer, Stanford University.

   Mr. Wyckoff has been with the project for the entire period covered by this report, and has spent 100 percent of his time on the project. Biographical data was included in the last annual report.

REPORTS AND ARTICLES

One technical article entitled, "Rapid Solids Determination Using Glass Fiber Filters" by Bruce M. Wyckoff was published in the June, 1964, issue of Water and Sewage Works. The work which went into writing of the article and development of the method was supported in part by this project.

In April of 1964, a paper entitled, "Water Renovation by Ion Exchange," was presented at the California Water Pollution Control Association in Fresno, California, by Mr. Wyckoff. This paper describes work done in connection with this project. It has been submitted for publication to the Journal of the Water Pollution Control Federation.

ACKNOWLEDGMENTS

The work accomplished on this project would be impossible without the assistance of a great many others. Particularly to be thanked are the equipment manufacturers who provided equipment for the pilot plant at no cost to the project. Chicago Pump Company supplied the activated sludge unit, set the unit up for operation, and provided continuous help and advice since then. Infilco has provided the chemical treatment unit, sand filter, and ion exchange unit, and assisted in putting these units into operation. DeLaval has supplied the diatomaceous earth filter. Worthington Corporation supplied the pump for filter backwash.

The Diamond Alkali Company, Western Division, Redwood City, California, has agreed to provide the necessary ion exchange resin. Stauffer Chemical Company has provided lime and alum for chemical treatment. Johns-Manville Products Corporation is providing diatomaceous earth, and Leslie Salt Company is providing salt.

In the laboratory, BIF Industries provided a small chemical feed pump which was used to return activated sludge. California Research Corporation, Richmond, California, donated the foamer. Diamond Alkali Company provided ion exchange resins, Dow Chemical Company provided samples of coagulant aid materials, and Pittsburg Chemical Company supplied activated carbon.

The assistance and advice of Dr. Irving M. Abrams of the Diamond Alkali Company in connection with the ion exchange studies is appreciated. The project is being carried out in cooperation with the City of Palo Alto. The help of Ludwig Huebner, plant superintendent, is gratefully acknowledged.

REFERENCES

1. "U.S. Public Health Service Drinking Water Standards, 1962," Public Health Service Publication No. 956.
2. Bernstein, L., "Tolerance of Plants to Salinity," Transactions American Society of Civil Engineers, Vol. 128, Part III, p. 561 (1963).
3. Abrams, I. M., and Lewon, S. M., "Removal of ABS from Water by Chloride Cycle Anion Exchange," J. American Water Works Association, Vol. 54, pp. 537-43 (May 1962).
4. Abrams, I. M., private communication.
5. Sharman, S. H., Kyriacou, D., and Searle, D. P., "Increased Alkylbenzene Sulfonate Removal from Sewage by Foam Recycle," presented at the 36th Annual Convention, The Soap and Detergent Association, on January 24, 1963 in New York.
6. Ludzack, F. J., and Ettinger, M. B., "Controlling Operation to Minimize Activated Sludge Effluent Nitrogen," J. Water Pollution Control Federation, Vol. 34, No. 9, p. 920 (September, 1962).